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Enhance sensitivity of plastic optical fiber sensor by spiral configuration for body temperature applications

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Abstract. In this study, sensors to measure body temperature were made using a macro bending method based on plastic optical fiber. Fiber optic sensors are made to form a spiral configuration on variations in diameter and bend number. The body temperature sensors are mounted on the elastic cloth and placed on the armpit. The light from the LED transmitted into an optical fiber sensor is affected by body temperature, so there is power loss in the sensor. Power loss cause light intensity decreases received by the phototransistor and differential amplifier. The power loss of the sensor and temperature measurement results will be displayed on the computer through the Arduino Uno microcontroller. The range of temperature used is 28°C - 42°C. The best sensor characteristic obtains at the spiral configuration in a diameter of 0 cm with some bending four bends and a range value of 0.421 V, sensitivity of 30.071 mV/°C, and resolution of 0.033°C. Plastic optical fiber is very suitable to be used as body temperature sensors because it can enhance sensitivity.

1. Introduction

Monitoring body temperature is very important to know the body health condition. In this activity, an electronic device based on a sensor is needed that can be used to measure body temperature. At present, many sensors are used to measure body temperature including electric temperature sensors. This sensor has several disadvantages, namely a long reading time so it cannot produce results in real-time. Body temperature measurements can be done in several places such as placed in the armpits (axilla). Measurement of body temperature can use an electronic contact thermometer with a monitoring mode of the disposable probe. The position of the thermometer placed on the armpit is pressed by the arm attached to the chest until the temperature is balanced [1]. Modern devices for measuring body temperature in the armpit might have changed the normal body temperature range. Body temperature in the armpit has a variation caused by changes in the method of measuring by modern devices and techniques. Temperature variations in the armpit can also indicate fat mass and changes in the menstrual cycle [2-3].

Several studies have been carried out using optical fibers, such as Fiber Bragg Grating (FBG) sensors to monitor body temperature during medical treatment using radio frequencies. This tool has the disadvantages of high cost and low accuracy [4-5]. Temperature measurement is based on a Mach-Zehnder interferometer to monitor body temperatures that have a complex connection process [6]. The temperature sensor is based on Long Period Grating (LPG) optical fiber which has low sensitivity [7]. The body temperature sensor uses FBG which focuses on sensor sensitivity. This sensor has the



disadvantage of high cost and low sensitivity [8]. Another study in temperature measurement using multicore optical fiber but has complicated methods [9].

In this research, the sensor focus on measuring body temperature based on plastic optical fiber (POF) with a variable number of bends, diameter, and temperature. This variety causes power losses in optical fiber [10]. The temperature sensor then determined the value of the range, sensitivity, and resolution. A large range of power losses in the sensor can enhance sensitivity. The advantage of using plastic optical fiber as a sensor is a simple measurement method and accurate. This research is expected to produce better characteristics of a body temperature sensor, such as high sensitivity, easy fabrication, and low cost.

2. Research Methodology

In this study, the body temperature sensor uses POF with a variable number of bends, diameter, and temperature. The main ingredients of the sensors are POF, Light Emitting Diode (LED), and phototransistor. LED as the light source with type IF-EA91A infrared which has the function to transmit the light at a wavelength of 950 nm. The POF used is made from polymethyl methacrylate (PMMA) material with a multimode step-index type. POF layer consists of a jacket, cladding, and core with diameter 2.2 mm, 1 mm, and 0.98 mm, respectively. The refractive index of core 1.492, a cladding refractive index of 1.402, and a numerical aperture (NA) value of 0.5. Whereas, an IF-D92 type of phototransistor has a function to receive light from the LED [11].

The working principle of the body temperature sensor refers to changes in the coefficient of thermal expansion and macro bending method. In this research, the design and manufacture of temperature sensors based on POF without a jacket. The sensor mounted on an elastic cloth was then placed on the armpit and at pre-set temperature conditions. LED and phototransistors are connected to each end of the POF. Changes in body temperature and macro bending will cause physical changes in the optical fiber and the light from LED that propagate in POF will decrease. The light intensity from LED is then received by the phototransistor and amplified by a differential amplifier. The output from the differential amplifier is then converted by the microcontroller Arduino UNO and the output result displayed on the computer in the forming voltage. The block diagram body temperature sensors can be seen in Figure 1.

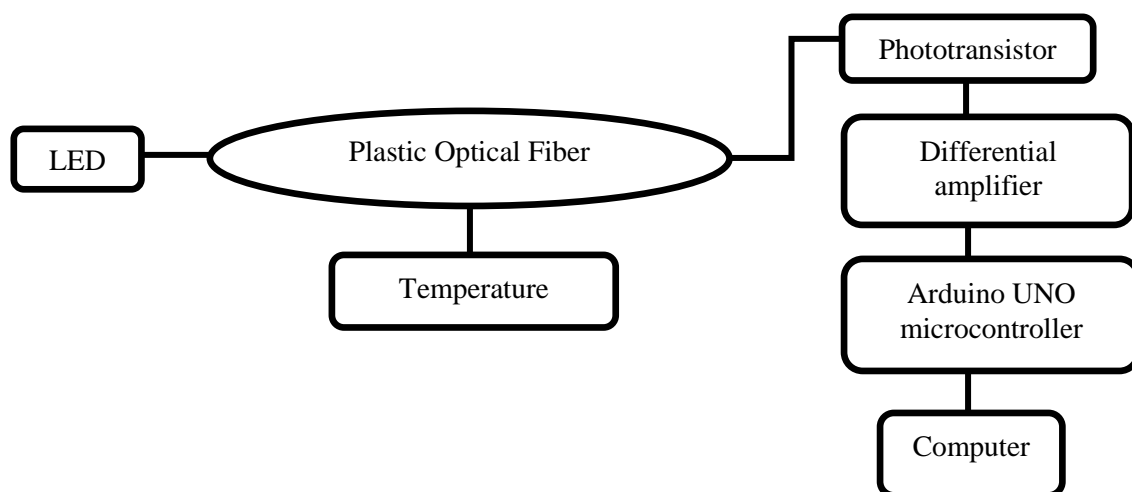


Figure 1. Block diagram of body temperature sensors.

Sensor testing is done with a variable number of bends, diameter, and temperature. The sensor is made is designed by using a macro bending method with spiral configuration and the length of optical fiber used is 25 cm. For the spiral configuration used 2 types of variation, i.e. diameter and the number of bends. For variations of diameter has been used 0 cm, 0.5 cm, and 1 cm. While for variation in the

number of bends used 2, 3, and 4 bends. The optical fiber sensor without coat mounted on the elastic cloth and placed on the armpit as shown in Figure 2.

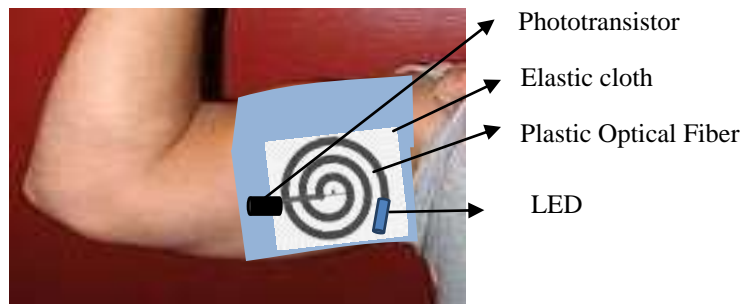


Figure 2. Body temperature sensor using spiral configuration.

Furthermore, the sensor is mounted to an elastic cloth, then placed on the armpit, and set the desired temperature conditions. The temperature sample used ranges from 28°C - 42°C with an increment of 1°C for each measurement. The output from the sensor in the form output voltage is then displayed on the computer. The temperature and output voltage changes can be used to determine the characteristics of each sensor.

3. Results and discussions

Measurement was made using a various number of bends, diameter, and temperature. The testing process is carried out with spiral configuration and temperature sample range from 28°C – 42°C with an increment of 1°C for each measurement and sensor were made. Two parameters characterize the effect of temperature on optical fibers, namely the Thermal Expansion Coefficient (TEC) and the Thermo-Optic Coefficient (TOC). The TEC characterizes physical expansion or contraction of material volume, while the TOC characterizes the change in the refractive index in the response of temperature changes. By using TEC and TOC, changes in optical fiber length (L), core radius (α), and refractive index (n) due to temperature changes can be expressed as [12].

$$\Delta L = \alpha L \Delta T \quad (1)$$

$$\Delta a_{(SMF,MMF)} = \alpha a_{(SMF,MMF)} \Delta T \quad (2)$$

$$\Delta n_{(SMF,MMF)} = \beta n_{(SMF,MMF)} \Delta T \quad (3)$$

Where, α and β are the TEC and the TOC. Δn is the change in the refractive index due to changes in temperature ΔT . Plastic optical fiber has $\alpha = 7 \times 10^{-5} / ^\circ\text{C}$ and $\beta = -1.2 \times 10^{-4} / ^\circ\text{C}$ [13].

The temperature sensor based on optical fiber testing is done by placing the sensor on the armpit and set the desired temperature conditions with a span of 1 minute. The sensors test worked to get the best characteristics and then use to monitoring body temperature continuously. In this study, the sensor has been made using spiral configuration on variation in diameter and number of bends. The variation of diameter has been made uses 0 cm, 0.5 cm, and 1 cm. While the number of bends uses 2, 3, and 4 bends. Each measurement causes different characteristic response and the temperature measurement results displayed on the computer shown in Figure 3.

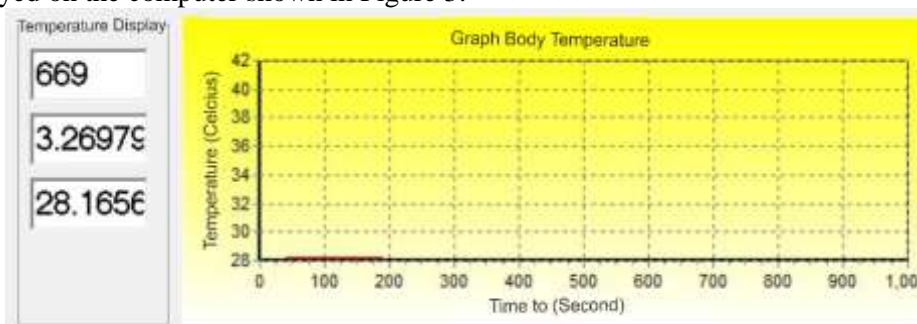


Figure 3. The results of the temperature measurement display on the computer

Figure 3 shows the temperature measurement result displayed on the computer. The upper column shows the binary number of the Arduino UNO, while in the middle is the output voltage in V units of the Arduino UNO, and the lower is the value of temperature that has entered. In this view, there is also a graph of temperature changes with the time. The extremely fast transmission of data from the Arduino UNO to the computer allows the real-time of temperature monitoring.

Temperature measurement starts at the sensor in a diameter of 1 cm with variations in the number of bends. The output result is displayed on the computer in the forming voltage. Furthermore, the output voltage of the sensor in a diameter of 1 cm with variations in the number of bends shown in Figure 4.

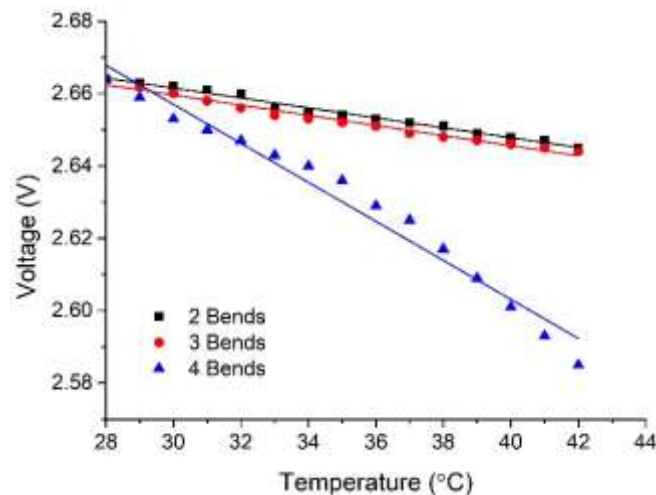


Figure 4. Graph of output voltage to body temperature changes in 1 cm diameter.

The graph in Figure 4 shows the change between body temperature and output voltage for spiral configuration in a diameter of 1 cm. In Figure 4, the black sign indicates 2 bends of the sensor, for red sign indicates 3 bends, and for 4 bends represented by a blue sign. The best result is obtained on the bends number of 4. The more bends of the sensor applied and the increase of temperature causes strain due to optical fiber. The strain then impacted the intensity of light in the optical fiber disrupted and cause loss of power. The increasing loss of power cause the light intensity received to become smaller so output voltage decreased. The next graph of the output voltage to temperature changes in 0.5 cm diameter with a spiral configuration shown in Figure 5.

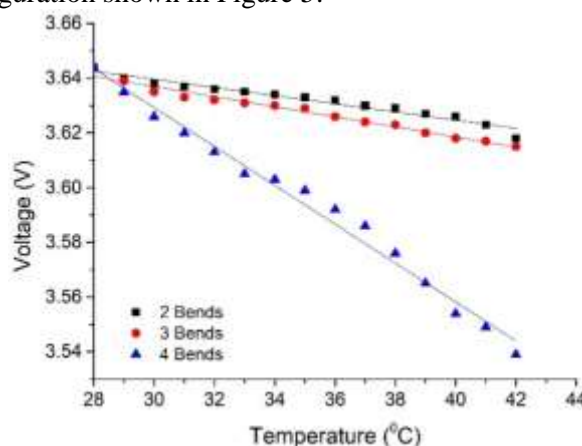


Figure 5. Graph of output voltage to body temperature change in 0.5 cm diameter.

The graph in Figure 5 shows the output voltage for a spiral configuration in a diameter of 0.5 cm. This graph has a similarity with the graph in Figure 4. The higher the temperature, the output voltage decreases. The graph shows that the best results in bends number of 4. Then, the study continued by using a 0 cm diameter in the various number of bends shown in Figure 6.

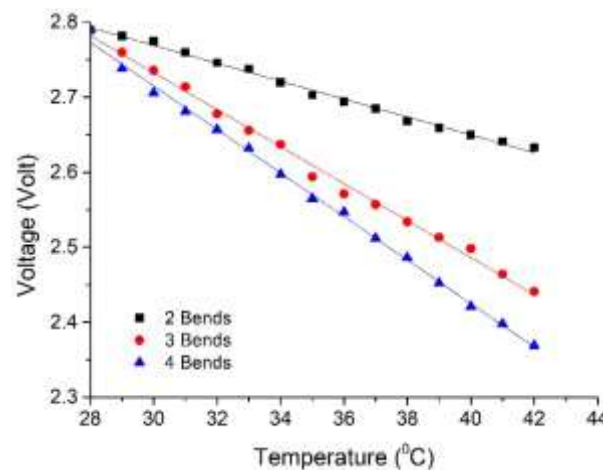


Figure 6. Graph of output voltage to body temperature changes in 0 cm diameter.

Figure 6 shows that the increase in temperature is inversely proportional to the output voltage of the sensor. The higher the body temperature that occurs, the output voltage of the sensor decreases. The graph shows that the plastic optical fiber sensor in 4 number of bends has the best result. All the best results for each diameter i.e. 1 cm, 0.5 cm, and 0 cm compared and shown in Figure 7.

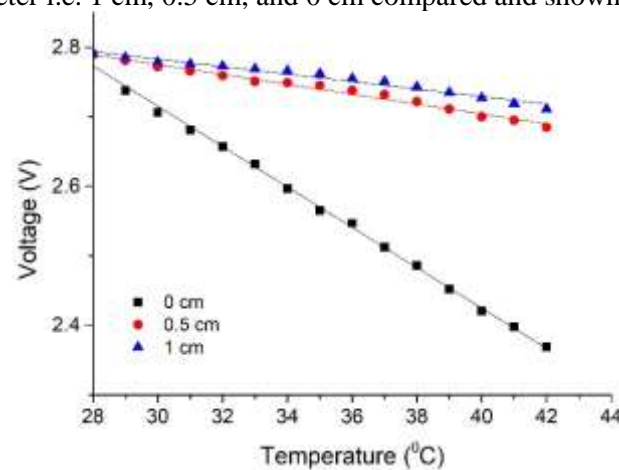


Figure 7. Comparison graph of the best results of diameter variations using 4 number of bends.

Figure 7 shows a comparison graph of the best results in the spiral configuration for each diameter, using 4 the number of bends. The best results in Figure 7 are obtained at a diameter of 0 cm. The graph shows that the temperature increases, the output voltage decreases. Theoretically, the greater the power losses from the sensor, the lower the output voltage. The power losses are obtained from the smaller diameter which is a macro bending method, as well as changes in body temperature causing thermal expansion on the sensor. Sensor characteristics include range, sensitivity, and resolution. The characteristics of the sensor can be calculated using the following equation [14-15]:

$$\Delta = V_{\max} - V_{\min} \quad (4)$$

Where, Δ is the range of sensor. Range is the maximum output voltage minus the minimum output voltage.

S (Sensitivity) is a measure that states the relationship between the change in the output sensor in form voltage and the change in the input of the instrument (K) [16].

$$S = \frac{V_{\max} - V_{\min}}{K_{\max} - K_{\min}} \quad (5)$$

Resolution is the smallest change that can be read by the sensor. The resolution can be calculated by dividing the smallest scale value of Arduino Uno (N) with the sensitivity value. The smallest scale value of Arduino Uno is 0.001 volts [14-15].

$$R = \frac{N}{S} \quad (6)$$

Characterizations of the body temperature sensor determined by using equation (1-6) shown in the Table 1. Furthermore, the sensitivity in mV/°C units and the resolution in °C units.

Table 1. Characteristics of the body temperature sensor spiral configuration.

Characteristics of sensor	Diameter of 1 cm			Diameter of 0.5 cm			Diameter of 0 cm		
	Bends Number			Bends Number			Bends Number		
	2	3	4	2	3	4	2	3	4
Range (V)	0.019	0.020	0.079	0.026	0.029	0.108	0.157	0.349	0.421
Sensitivity(mV /°C)	1.357	1.429	5.643	1.857	2.071	7.500	11.214	24.929	30.071
Resolution (°C)	0.737	0.700	0.177	0.539	0.483	0.133	0.089	0.040	0.033

Based on Table 1, it can be seen that the best characteristics of the sensor that have the highest range and sensitivity values but low resolution. The best results showed at a diameter of 0 cm in bends number of 4. The results obtained are range values of 0.421 V, the sensitivity of 30.071 mV/°C, and a resolution of 0.033°C. The comparison graph of sensitivity value to diameter variations shows in Figure 8.

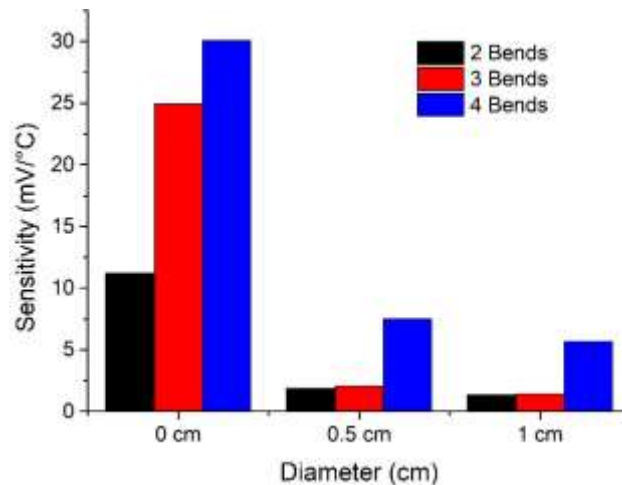


Figure 8. Comparison graph of sensitivity value to diameter variations

The measurement result can be seen in the comparison graph in Figure 8. This figure shows a comparison graph of sensitivity value at the various number of bends in 0 cm, 0.5 cm, and 1 cm. It is seen that the highest sensitivity value is shown in the 4 number of bends using 0 cm diameter. The sensors test worked to get higher sensitivity and better resolution. The data from the temperature measurement sensor produce a different response. The measurement starts from the variation of diameter using 1 cm, 0.5 cm, and 0 cm with three types number of bends i.e. 2, 3, and 4 bends. The best result of 1 cm diameter obtained sensitivity and resolution value of 5.643 mV/°C and 0.177°C respectively using 4 bends. The measurement then continued using a smaller diameter of 0.5 cm with a variable number of bends and obtained the best sensitivity and resolution value of 7.500 mV/°C and 0.133°C respectively using 4 bends. The last process carried out using the smallest diameter of 0 cm. The last process obtained the best result of this research with a sensitivity and resolution value of 30.071 mV/°C and 0.033°C.

The sensor with varying temperature, diameter, and the number of bends mounted on elastic cloth cause macro bending on the sensor. The more bending applied for the number of bends, smaller diameter, and the increase of temperature cause strain due to optical fiber. The strain on the optical fiber then impacted the intensity of light in the optical fiber disrupted and cause loss of power. The increasing loss of power causes the light intensity received by the photodetector to get smaller and the output voltage decreased which is displayed on the computer. From all processes in this study, we show that each variation obtained different output voltage and will produce different sensitivity and resolution values. This research has better results compared to previous studies Khan et al (2016) produce a low sensitivity value of 3.733 mV/°C [17]. Likewise by Palumbo (2016) about FBG for monitoring temperature during medical radio frequency treatment having a high resolution of 0.1°C [4]. This states that the higher the sensitivity and the lower the resolution, it will be better the characteristics of the sensor. POF is suitable for enhancing the sensitivity of sensors in the measurement of body temperature with the advantages are high sensitivity, easy fabrication, low cost, and simple measurement process.

4. Conclusion

Sensors have been made to measure and monitoring temperature using plastic optical fiber. This study produces a spiral configuration with varying diameter and number of bends. The best sensor characteristic values were obtained in a spiral configuration in a diameter of 0 cm with some four bends. The best results obtained are range values of 0.421 V, the sensitivity of 30.071 mV/°C, and the resolution of 0.033°C. The smaller the diameter of the spiral and the more the number of bends applied causes better characteristics of the sensor. POF can enhance the sensitivity of the temperature sensor. This sensor is suitable for measuring body temperature with the advantages of high sensitivity, low cost, easy fabrication, and simple measurements.

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