Temperature monitoring using polymer optical fiber with integration to the internet of things

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ABSTRACT
In this paper, a polymer optical fiber (POF) is applied for temperature measuring of water solution using a light source of 650nm. The aim is to analyse the impact of temperature variations on the output of POF sensor device in terms of output power and sensitivity. From the study, the POF sensor shows a linear trend when the temperature is increased from 30°C to 80°C with the sensitivity of the polymer optical fiber for output power to the temperature are 0.00973 dBm/°C or 0.0014797 nW/°C, for optical characterization and 0.0011 V/°C for electrical characterization. The integration of the Internet of Things to the system helps the user to monitor the temperature of various spaces anywhere at any time. The sensed values are controlled by Arduino Uno R3 and then sent to Blynk to provide wireless monitoring by the user.

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1. INTRODUCTION
The most commonly evaluated physical parameter in the process industry or in controlled environments is temperature. Therefore, accurate measurements are crucial to achieve stability. In many applications such as medical applications, laboratory materials research, electronic or electrical component studies, biological research, and geological surveys, precise measurements are necessary. Temperature sensor offers great benefits to the user to observe and control the real-time temperature of the surrounding [1-4].
Up to this time, sensors used to evaluate temperatures such as thermostats, thermocouples, thermometers and temperature resistance detectors are based on electronic methods [5]. These sensors are broadly employed in many fields including the industry, medical, modern agriculture, food and beverage, and home appliances [6-8]. Recently, optical sensor systems are seen as an alternative to these conventional, less flexible, and rigid electronic devices.

Fiber optic sensor is an innovation, which enables light changes guided by fiber optics to be observed when subjected to external physical, organic, chemical, or other parameters. The benefit of a fiber-optic-based sensor is a massive bandwidth capable of transmitting higher data than a conventional copper wire. Besides, it opposes the electromagnetic interference (EMI) and radio frequency interference (RFI) of wireless communication [9]. The sensor can even be placed in the remote area, competent to measure parameter at an inaccessible location and do not has an electrical charge that fits in a hazardous area [10, 11]. Furthermore, the sensor is easy to install for expansion and can deal with the application of a wide variation
of temperature [12-15]. Therefore, due to vast advantages, polymer optical fiber (POF) is applied in this project for temperature measuring using a light source of 650 nm. Several advantages of POF are that it has massive flexibility, easier handling, long length, compact size and lightweight, inaccessible installation, resistance to extreme environments and no interference with electromagnetic fields [16-18]. The integration to the internet of things (IoT) system at the receiver part helps the user to monitor the temperature of various space anywhere at any time. The detected sensor is controlled by Arduino Uno R3 microcontroller and then sent to the Blynk application to provide wireless monitoring for user notification. To the best of our knowledge, integrating the fiber optic sensor to the IoT platform is still new, and the feasibility of IoT technology is expected to boost the growth of fiber optic sensor.

2. EXPERIMENTAL

The temperature measurement is carried out in two stages, the optical characterization and the electrical characterization. Figure 1 shows the experimental setup for temperature measurement of optical characterization. For the setup, the input power of the red LED of wavelength 650 nm is connected to a POF sensor, while the other end is connected to optical power meter for detection. The aim for optical characterization is to observe the dependence of optical output power to the temperature variation. The sensor sensing area is fabricated by the etching process and dipped into a measuring liquid, where the beaker is placed on the hotplate. The length of the POF is about 1 m, with sensing area at the middle of the fiber is about 2 cm. Deionized (DI) water in the beaker is heated by using a hotplate to increase the temperature of the solution, while the output power is observed from the optical power meter. Origin Pro 8 software is used to plot the output results in a graph. The readings for DI water solution temperatures are repeated five times and average reading is taken as the final result. The sensor probe is cleaned with acetone liquid and dried before another liquid testing is done.

![Figure 1. Experiment set-up for optical characterization](image1)

For electrical characterization, the setup is as shown in Figure 2. The receiver circuit which consists of the main component of photodiode IF-D91 and a dual-rail to rail operational amplifier LM358P are used to amplify and convert the optical to an electrical signal. A dual-rail to rail operational amplifier (Op-amp), LM358P is chosen for the receiver circuit design due to high input impedance and a wide range of supply voltage that is provided in microcontroller Arduino Uno R3. Op-amp needed +5V and –5V supply voltages to operate. The inverting input of LM358P attaches to the photodiode and the non-inverting attaches to ground. The output rom the receiver will be in voltage value. The multimeter is employed for measuring the voltage as the temperature changes.

![Figure 2. Experiment set-up for electrical characterization](image2)
3. RESULTS AND ANALYSIS

3.1. Fabrication of POF sensor

In order to design the fiber optic sensor, the sensor’s probe has to be fabricated to make it possible
to sense the presence of a solution surrounding the core surface [19]. In this project, the change in
temperature of the water solution leads to a change in output power measurement. Hence, exposing the core
of fiber optic is necessary so that it is in contact with the surroundings by removing the jacket and cladding of
fiber optic. Polymer optical fiber cable with 1 meter length was used for the preparation of the fiber optic
sensor. As many 2 cm of fiber jacket was removed at the center of the cable by using a fiber cutter [20]. After
the fiber jacket was removed, the etching process was done to remove the cladding on the core of the fiber
optic by dipping the exposed area with Acetone solution [21]. The exposed core will perform as a sensor
probe. Finally, the cladding residue on the sensing area of POF was cleaned using an alcohol solution, which
was Isopropyl. An image analyzer was used to measure the sample’s diameter after etching is done with
initial core and cladding diameter measurement was 1016.216 μm.

Figure 3 shows the measurement of the core diameter of polymer optical fiber sensor probe. After etching time of 2 s, it was found that fiber core diameter was 982.422 μm. Since only a slight core
exposure is needed, the diameter observed is adequate to ensure the core is slightly exposed, due to the initial
diameter of the core is only around 1000 μm. Etching the fiber more than 2 s will cause the fiber to over
etched [22]. For instance, shown in Figure 4, with 8 s etching time, the core diameter was reduced to 906.757
μm. Further core thinning will tend to break the fiber, therefore 2 s was selected as the best etching time.

![Figure 3. Etching side view measurement of fiber sensor probe for etching time=2 s](image)

![Figure 4. Etching side view measurement of fiber sensor probe for etching time=8 s](image)

3.2. Optical measurement of liquid temperature

For the optical characterization of the temperature, the POF sensor was connected to a light source
of a red light-emitting diode (LED) whilst another tip end was connected to the optical power meter (OPM)
to measure the output power. In this experiment, the light source of a red LED of wavelength 650 nm was used. Figures 5-6 show the graph of optical power in dBm and nanoWatt (nW) against the temperature. Five samples of data were collected for each temperature reading to get better accuracy. The graph in Figure 5 shows that the rise of the temperature has resulted in the rise of the output power in dBm. Figure 6 also shows a linearly increasing graph. When the temperature was increased, the output power in nW increased too. The result can be related to the previous research by A. Tapetado [9], Luo [23], and Leal [24], showing similar trend, whereas the temperature of the surrounding medium is increased, the power variation also increased.

From both Figures 5 and 6, they show the mathematical model to estimate the sensor performance can be estimated. The linear fit best line of both figures has the general mathematical equation as:

\[ y = mT + c \]  

where:  
\( y \) = Output power  
\( T \) = Temperature of water  
\( C \) = y-intercept in line graph

The equation represents the y as the output power, T as the temperature of the water and c as the y-intercept in the line graph. Table 1 shows mathematical modelling for optical measurement against the temperature of the water. From the mathematical modelling, the sensitivity of the polymer optical fiber sensor can be determined by the gradient of the graph, which is 0.00973 dBm/°C or 0.14797 nW/°C.

| Parameter   | Mathematical Modelling                   |
|-------------|------------------------------------------|
| Optical (dBm) | \( P(\text{dBm})=0.00973 \, T - 42.33422 \) |
| Optical (nW)  | \( P(\text{nW})=0.14797 \, T + 57.97183 \) |

### Table 1. Mathematical modelling for optical measurement

#### 3.3. Electrical measurement for liquid temperature

For electrical characterization, the input source of light of red LED with wavelength 650nm was supplied to the polymer optical as input whilst the tip end of POF was attached to a receiver circuit, which consists of a photodiode and an amplifier for output voltage measurement. A digital multimeter was used to measure the voltage. Table 2 shows the voltage measured in volts (V) for temperature from 30°C to 80°C. Five samples of data are collected for each temperature reading. The table summarizes the average reading of the output voltage in volt (V). Based on Table 2, the output voltage gradually increased when the temperature was increased.
Table 2. Measurement of the output voltage at different temperatures

| Temperature (°C) | Output voltage (V) |
|-----------------|---------------------|
| 30              | 0.566               |
| 35              | 0.574               |
| 40              | 0.578               |
| 45              | 0.583               |
| 50              | 0.589               |
| 55              | 0.594               |
| 60              | 0.596               |
| 65              | 0.603               |
| 70              | 0.610               |
| 75              | 0.621               |
| 80              | 0.632               |

Figure 7 shows the graph of output voltage versus the water temperature. The line graph of the figure shows a linear result. The rise of the temperature of the water has resulted in the rise of the output voltage in Volts. The result can be verified by [25], which shows the similar trend for liquid temperature measurement. Table 3 shows the mathematical modelling for electrical measurement for water temperature monitoring. From the mathematical modelling, the sensitivity of the polymer optical fiber in terms of the output voltage to the temperature variations was 0.00110 V/°C.

Table 3. Mathematical modelling for electrical measurement

| Parameter | Mathematical modelling |
|-----------|------------------------|
| Electrical (V) | P(v) = 0.00110 (T) + 0.53354 |

3.4. Integration with IoT

The block diagram connecting the optical sensor to the IoT platform is illustrated as in Figure 8.

Figure 7. Output voltage (V) versus temperature (°C) graph

Figure 8. Graph Block diagram of IoT integration to POF sensor

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The voltage value from the receiver circuit is sent to the control unit, which consists of Arduino UNO R3 microcontroller and cloud platform. The printed circuit board (PCB) layout of the receiver circuit in Proteus 8 software design is shown in Figure 9, whilst the wireless network circuit is shown as in Figure 10. The project was supplied by using a red LED of 650nm as the input power for the POF sensor. The LED was turned on using voltage supply +5V DC from microcontroller Arduino Uno R3. In this system, ESP8266 was used to connect the Arduino Uno R3 microcontroller with a wireless network.

A wireless network is needed to send all the data to the cloud platform. The cloud service chosen for this system is Blynk. All the values detected by the sensor were sent to Blynk through a wireless network. Blynk is also functioning as the mobile application for the user to monitor the output voltage of the electrical signal of the fiber optic sensor. The value detected by the sensor was read and the value will be displayed on the mobile phone. The reading of the POF sensor output voltage can be viewed through the Blynk Application to make it easier for the user to monitor wirelessly. Figure 11 shows an example of an output display on the Blynk application from a smartphone.

Figure 9. Schematic circuit of the receiver circuit

Figure 10. Wireless network circuit

Figure 11. An example of the voltage display on the smartphone by the Blynk application
4. CONCLUSION

A temperature sensor based on fibre-optic technology has been designed and tested. The research has been accomplished with an environmentally safe prototype by using POF has been developed. This fully functional temperature monitoring system with the integration to the IoT technology has been successfully tested for temperature measurement in the range of 30°C to 80°C. The outputs show a linear response of output power and voltage to the changes in temperature. It was concluded that as the temperature increased, the higher the output power and output voltage of the fibre optic sensor. The sensitivity of the polymer optical fiber determined in this study was 0.00973 dBm/°C or 0.14797 nW/°C for optical characterization and 0.00110 V/°C for electrical characterization. Future works will be emphasized on a deeper analysis of IoT temperature monitoring mechanisms, including multiple sensors and environmental effects.

ACKNOWLEDGEMENTS

Our thanks to Universiti Teknikal Malaysia Melaka (UTeM) for the support.

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