Intensity-based Macro-bend Plastic Optical Fiber Sensor using Raspberry Pi Platform

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Abstract: ***This paper presents an optical fiber sensor-based instrumentation system to measure the light intensity due to different refractive indices. The proposed sensor system consists of (i) He-Ne Laser as a source (ii) Fiber optic cable (iii) CCD camera to capture the intensity (iv) Raspberry Pi using phyton for processing. The optical fiber is bent into different radius and the intensity is captured every time the fiber is bent by the CCD camera. The Raspberry Pi use the phyton codes to process the captured intensity and plot it in the Gaussian curve. This sensor can be used for sensing the intensity of different solutions with different refractive indexes.***

Keywords: Attenuation; CCD camera; Gaussian plot; He-Ne Laser; Macro bending; Raspberry pi.

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1. Introduction

The fiber optic sensors use optical fiber as a sensing element [1-2]. These sensors are used to sense some quantities like temperature, pressure, vibrations, displacements, rotations or concentration of chemical species [3]. Fibers have so many uses in the field of remote sensing because they require no electrical power at the remote location and they have tiny size.

Fiber optic sensors are supreme for insensitive conditions, including noise, high vibration, and extreme heat, wet and unstable environments. These sensors can easily fit in small areas and may be positioned correctly wherever flexible fibers are needed. There are many advantages of using fiber optic sensors for long-distance communication that include small in size, light in weight, compactness, high sensitivity, wide bandwidth, etc. All these characteristics make the best use of fiber optic as a sensor. Transmission and distribution transformers are a number of the foremost critical and expensive assets during a power network. There are many reasons why high voltage transformers might fail, and one important possibility is that the deterioration of the insulation [4]. Water is a contaminant that has long been recognized as a major cause of trouble. If a small quantity of moisture is left in the dielectric, it acts to degrade the insulation and in turn produces more moisture due to chemical action.

Power transformers are one of the foremost expensive investments in electrical power systems. They are fundamental components of electrical power systems, and their reliability is an important factor in the operation of the system. The transformer oil is a good insulating material. However, some factors like water and gas can contaminate the oil. There have been many techniques developed for the detection of moisture content in the transformer oil such as partial discharge method [5], chromatography [6], infrared spectroscopy [7] etc. The moisture content in the transformer oil sample can be related to the change in the refractive index of the sample. In fact, the measure of the refractive index provides information about the turbidity of the liquid.

This paper describes the study of macro bending of the optical fiber which can be used as a sensor by controlling it with microcontrollers and in this Raspberry pi has been used. This sensor can be used for sensing the intensity of different solutions with different refractive indexes.

2. Macrobending Theory

When a multimode fiber is put at a sharp bend (macrobend) with a radius of curvature exceeding the critical radius of curvature, light rays are lost in the cladding, which results in power loss and attenuation. Since higher modes are bound less tightly to the fiber core than the lower order modes, the higher-order modes radiate out of the fiber first resulting in loss of attenuation [7, 8].

Attenuation or power loss (α):

$$\alpha = \frac{loss}{fiber\ length}$$

$$= -10\,\frac{\log\left(\frac{P_{out}}{P_{in}}\right)}{l}$$

$$\Rightarrow \frac{\alpha l}{10} = \log_{10}\frac{P_{out}}{P_{in}}$$

$$\Rightarrow \frac{\alpha l}{10} = -2.303\,\log_e\frac{P_{out}}{P_{in}}$$

$$\Rightarrow e^{-\alpha l 2.303} = \frac{P_{out}}{P_{in}}$$

$$\therefore\ P_{out} = P_{in}\,e^{-\alpha l 0.2303} \qquad \text{------------------ (1)}$$

This is the expression for single-mode fiber.

From equation (1), we have found out power output depends only on the attenuation value, since the length of the optical fiber and input power (laser) are constant. With the increase in attenuation power output decreases and attenuation depends upon the radius of curvature of the bend.

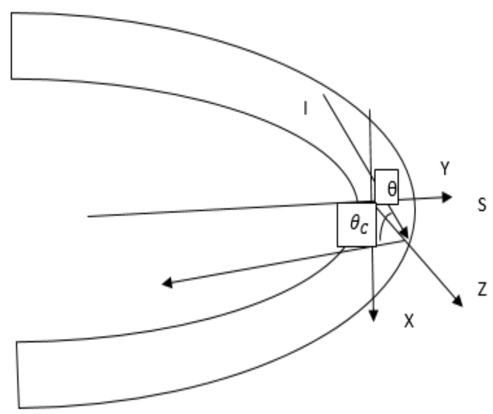

Figure 1: Description of coordinate system in analyzing attenuation ratio for incident ray I

Figure 1 shows the attenuation of the light ray passing through the fiber where the cladding has been removed and bent. The incident angle θ to the area S, where the cladding is stripped off, is given by $\theta = \arcsin\,[\cos \propto \cdot (R+h)/(R+2a)]$, where a is the radius of the fiber and R is the bending radius. When $\theta \geq \theta_c = \arcsin\,(n_m/n_{co})$, the ray I is totally reflected and continues to propagate in the fiber. Here, θ_c= critical angle, n_m= refractive index of the medium, n_{co}= refractive index of the core. But when $\theta < \theta_c$, most light is transmitted into the surrounding medium. To investigate the dependence of the attenuation ratio on n_m, we make assumptions that the light intensity is uniform across the core and the reflectivity at S equals zero for partially reflected rays.

Therefore, the critical angle θ_c at which incident light emerges from the core of the sensor to the surrounding medium is given by $cos\theta_c = \sqrt{1-(n_m/n_{co})^2}$. So, the rays satisfying the inequality $cos\theta \leq cos\theta_c$, that is,

$$\frac{\sqrt{a^2-x^2}\cdot\sqrt{2(R-a)(\sqrt{a^2-x^2-y})+a^2-x^2-y^2}}{a(R+a+\sqrt{a^2-x^2})} \leq \sqrt{1-(\frac{n_m}{n_{co}})^2}$$

are totally reflected at the sensor surface S [9]. This indicates that this sensor is effective for the measurement of the refractive index under n_{co} by changing the bending radius R appropriately.

The relative sensitivity of the sensor is $\left(\frac{1}{\mathrm{E}}\right)\mathrm{dE}/\mathrm{d}n_m$, where E is the emergent energy. The results indicate that as the refractive index of the surrounding medium n_m is close to the core n_{co}, large sensitivity can be obtained.

3. Description of the experimental setup

The experimental setup shown in Figure 2 consists of the He-Ne laser as the source, it has a fiber optic cable that acts as the path for the light to travel and part of it is cladding is stripped off and is inserted inside the cuvette. The cuvette will be filled with different samples of different refractive indexes to check the sensitivity. The CCD camera is at the other end of the fiber to capture the intensity of the light. The capturing of the light intensity is controlled by Raspberry pi and the output is shown on the PC.

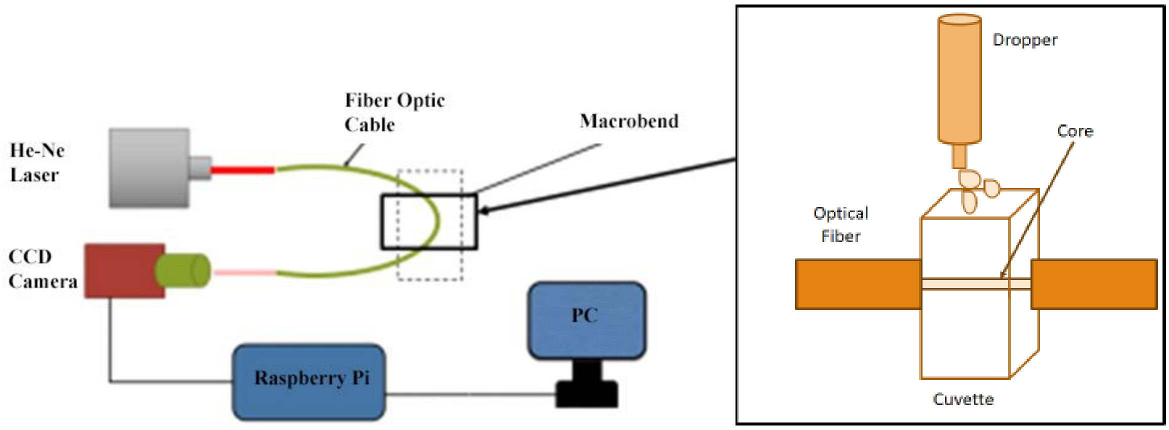

Figure 2: Proposed Setup

The optical fiber used here is a plastic optical fiber cable. The part of an optical fiber about 0.5 cm is stripped off by a clipper and then to remove the cladding it is soaked in alcohol and wipe with a tissue to get a smooth surface. The sensitivity of the sensor to the refractive index is dependent on cladding thickness. The part of the optical fiber where the cladding is removed is inserted inside the cuvette and it is sealed with the help of the glue gun. He-Ne laser acts as a source is turned ON and allowed to pass through the optical fiber cable. The optical fiber is bent with a radius of curvature of 6.5 cm. The distance from the end of the optical fiber to the CCD camera is 4.5cm. The codes in Python have been written for the capturing of the intensities by clicking of a mouse. The different specimen samples have been used one after the other and the readings are recorded and saved. The saved spectrum is plotted in the Gaussian curve shown in figure 4.

Figure 3: Top view of the designed setup

4. Results and Discussion

The experimental arrangement is shown in Figure 2. A light beam emitted by He-Ne Laser (5 mW) is incident on one end of the fiber. The emerging light is detected by a CCD camera at the other end of the fiber.

Air, distilled ionized water and 20% of glycerol are employed as specimen samples to investigate the characteristic of the sensor. These three samples have different refractive indexes which will be used to check the sensitivity of the sensor according to the different refractive indexes. Air has got a refractive index of 1, distilled water has 1.33 as the refractive index and 20% of glycerol has a refractive index of 1.35.

The experimental results plotted in the Gaussian curve are shown in Figure 4. As theoretically predicted, the normalized attenuation ratio γ_n becomes larger according to the increase in n_m and decrease in R/a. Therefore, once the relation between γ_n and n_m is determined experimentally, each sample can be distinguished by the difference in γ_n for the same bending radius R [10, 11].

The intensity for a different radius of curvature has also been observed and compared with straight optical fiber to see the difference as shown in Figure 5. It has been observed that for a different radius of curvature the intensity changes. As the radius of curvature decreases the intensity also starts to decrease. Therefore, we have compared it with a straight fiber and found out the difference in the intensities when we bend the optical fiber.

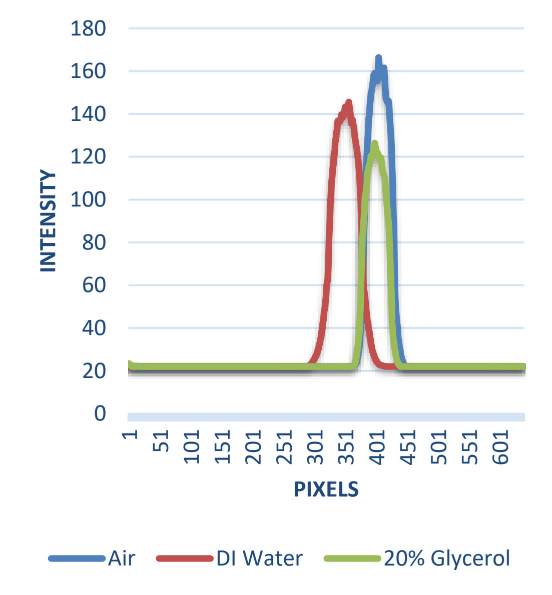

Figure 4: Intensity vs pixels graph of the three samples air, DI water and 20% glycerol

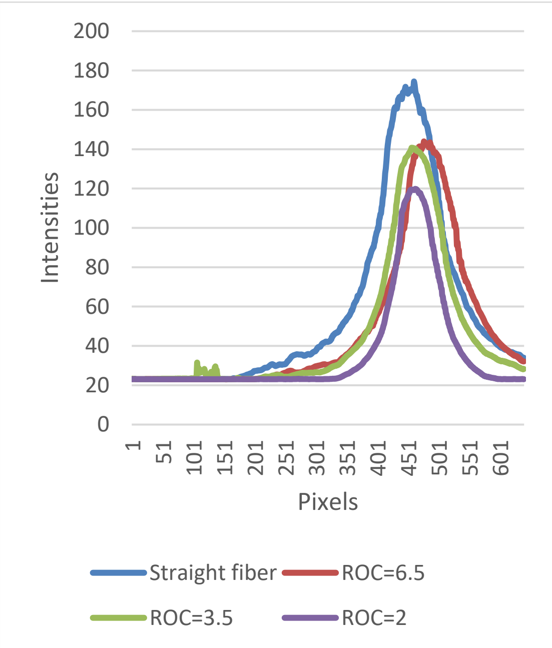

Figure 5: Intensity vs Pixel's graph for different radius of curvature (ROC)

5. Conclusion

The optical fiber stripped off its cladding act as a good sensing element with a certain bend in the fiber. The characteristic of the fiber sensor, in particular, the slope of the sensor output signal to RI change have been investigated. With the help of three specimen samples that we have used, we have observed the intensity is changing with respect to the refractive index. Also, we have observed that the more the bending of the fiber, the more is the loss taking place in the fiber and the intensity decreases. As a result of this investigation, we conclude that these sensors are easy to fabricate and handle, are highly sensitive to RI change and are sensitive over a wide range of RI.

6. Future Research

The research presented in this paper prevailed over some of the awaiting processes. The proposed setup is lab-based and to make it available commercially the source can be replaced by high intensity LED which will make it portable. The CCD camera which has been used can also be replaced with a higher megapixel camera like a CMOS camera of about 3-5 megapixels to capture better intensities and observe the power loss. This work can be further used for sensing the moisture content of the transformer oils.

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