Advanced Research in Electrical and Electronic Engineering
p-ISSN: 2349-5804; e-ISSN: 2349-5812 Volume 3, Issue 5, October-December, 2016, pp. 404-407

http://www.krishisanskriti.org/Publication.html

Intensity Modulation based Measurement of Refractive Index of Colorless Liquid using Optical Fiber

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Abstract—*Refractive index (RI) is a unique property of liquid or material. It is one of the important physicochemical properties of substances which provide information about the behavior of light. A cost effective system of measuring refractive index of a sample solution has been described here. Two optical fibers, one as transmitter and another as receiver is connected to a black glass chamber used for holding the sample liquid. Light from a He-Ne source is launched at one end of the transmitting fiber of which the other end is connected to one face of the glass chamber. The receiving fiber, connected to the opposite face of the glass chamber, collects a part of the refracted light passing through the sample solution. The light at the other end of the receiving fiber is detected by a photo detector. The output of the photo detector is calibrated in terms of voltage corresponding to the refractive index of the sample solution. By repeating the measurement for a number of times for different types of liquids, a precise voltage vs. RI curve is achieved. This voltage range can be calibrated to indicate the refractive index of that specific solution. The voltage range is again fed to an Arduino UNO board to display the refractive index of the sample solution.*

1. INTRODUCTION

Fiber-Optic Sensors have attracted enormous interest now-a-days due to their wide application in sensing of parameters like physical, chemical, biotechnology etc. The main drive of research in this area is to provide a foundation for an effective measurement technology, which can complete with conventional methods. Fiber optic sensors offer advantages like rapid response, compact size, and immune to electromagnetic interference. Therein lays the success of optical fiber sensors—in tackling difficult measurement in situations where conventional sensors sometimes fail to do so[1,7].

Measurement of liquid refractive index is critical for various industrial applications. A wide range of optical fiber sensors based on refractive index measurement has been reported in the literature [2-8]. A type in [2] uses three parallel fibers and a mirror.

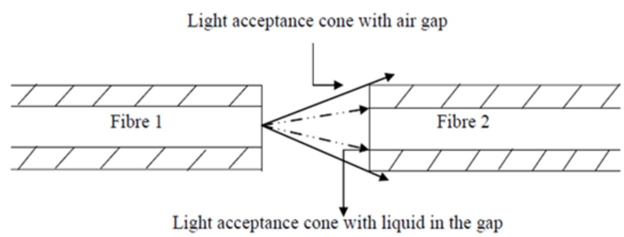

Fig. 1: A basic configuration of an optical fiber refractometer.

Its principle of operation is based on the output light angle change due to the refractive index of the liquid into which the optical fiber probe is dipped. Another type has been described in [3] which use two fibers, mirror as reflector and liquid as medium. The light is carried by the illuminating fiber up to modulation zone where the properties of incident light is modulated by modulator. The modulated light is carried by receiving fiber to the detector. The measurement principle is based on reflective intensity modulation. In [4], an optical fiber, partially stripped of its cladding is shown to sense refractive index of a liquid in which the un-cladded sensing region is immersed. The sensitivity of the sensor to refractive index change is dependent on cladding thickness and is a maximum at an intermediate thickness value. The intensity of light signal transmitted through an optical fiber, whose cladding over a finite length is removed, is used as a sensor of refractive index of liquids in [5], in which the fiber is immersed. The transmitted light intensity is measured as a function of liquid refractive index for different lengths of the unclad section of the fiber and at each unclad length its sensitivity to change in refractive index of liquid is monitored.

In this paper, a simple intensity modulation based fiber optic sensor has been reported for measurement of refractive index of colorless liquids. It briefly covers the principle of working, experimental setup followed by result analysis and conclusion.

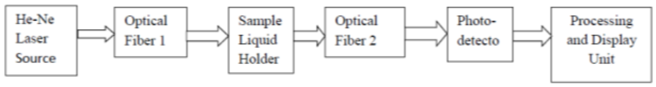

Fig. 2: Block diagram representation of the proposed system.

2. PRINCIPLE OF MEASUREMENT

Intensity-based fiber optic sensors rely on signal under-going some loss. Generally they are related to the displacement or some other physical perturbation that interacts with the fiber. The perturbation produces a change in received light intensity. The change of the optical intensity can be related to transmission, reflection, microbending and other phenomena such as absorption, scattering, or fluorescence. Intensity based fiber optic sensors can be divided into reflection sensors, transmission sensors and microbending sensors. This type of sensors are inherently simple and require simple electronic support [6]. The intensity-based sensor requires more light and therefore usually uses multimode large core fibers [3]. There are a variety of mechanisms such as microbending loss, attenuation, and evanescent fields that can produce a measurand induced change in the optical intensity propagated by an optical fiber. The advantages of these sensors are: Simplicity of implementation, low cost, possibility of being multiplexed, and ability to perform as real distributed sensors. The drawbacks are: Relative measurements and variations in the intensity of the light source may lead to false readings, unless a referencing system is used.

Optical fibers have been used to measure refractive index of a liquid through intensity modulation of light by the measurand. In the Fig. 1, light is seen to get partially coupled to fiber 2 from fiber 1 through a fixed air gap. Light ejected out from the fiber 1 will be collected by fiber 2. But due to the presence of the air gap between the two fibers, only a fraction of the light will reach fiber 2. When the air gap is filled with a colourless liquid medium, the transmittance of light will be dependent on the refractive index of the medium.

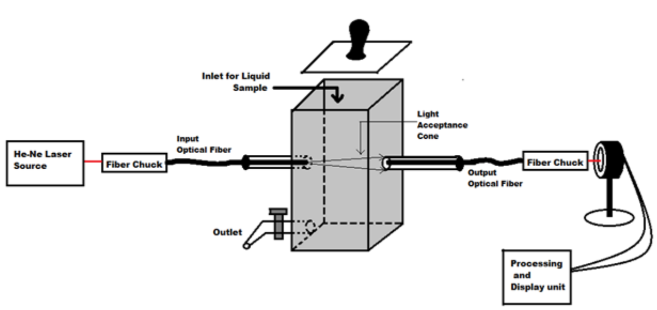

Fig. 3: Diagrammatic representation of the designed system

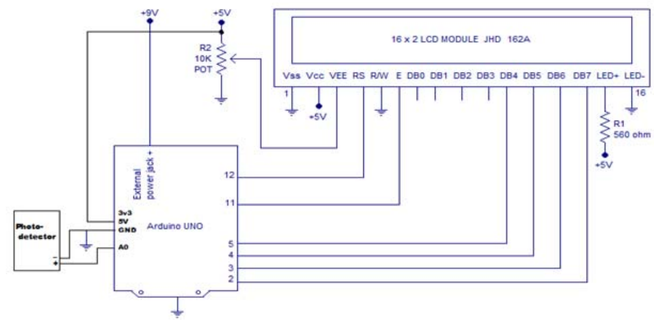

Fig. 4: Arduino Interfacing with LCD

As numerical aperture is a function of the index of refraction of the medium outside the fiber, the divergence angle of light from fiber 1 will decrease with increase in RI of the liquid medium. Hence a greater fraction of the light emitted by the fiber 1 will be picked up and guided by fiber 2 due to effective decreases in numerical aperture. The ratio of the power collected by the fiber 2 through the liquid than through air is a linear function of the refractive index of the liquid. This configuration has been also used to detect acid level in batteries and for that matter as a threshold liquid level sensor because, with and without the liquid in the gap between the two fibers, the signal level at the output of the fiber 2 will be different.

3. EXPERIMENTAL SETUP

The block diagram of the designed system is shown in Fig. 2 and a diagram of the experimental setup is shown in Fig. 3. A He-Ne LASER (632.8 nm wavelength), whose intensity is higher compared to the diode laser, is used as the light source. Light beam coming from the source is projected to optical fiber 1. The other end of the fiber is embedded to one side of a black glass cuboidal chamber that holds the liquid sample under test. From the other side of the chamber, a receiving fiber collects the light coming through the sample and the other end of the fiber is aligned to a photo detector. The output of the photo-detector is first checked and then it is applied to an arduino development board for processing of the output voltage signal and LCD interfacing. The LCD is connected to the Arduino board in 4-bit mode. A 10K pot is connected to the LCD for adjusting its contrast. The analog output from the photodetector is given to analog pin A0 of the Arduino board. The internal reference voltage of the Arduino board is set to 1.1V. The LCD displays the refractive index of the sample liquid present in the black chamber. Fig. 3 shows the arrangement of the setup and Fig. 4 shows the Arduino interfacing circuit.

4. RESULT ANALYSIS

For analyzing the designed system, the setup was first referenced with air as medium in the glass chamber. As there is no other referencing signal used in the setup, therefore to reduce the error, a high power laser source of 1mW power is used. Then water was poured slowly into the empty cuboidal glass arrangement without disturbing the setup. The voltage of the photodetector is recorded when it gets stable. Then the water is drained out through the outlet. Five sets of readings are taken by repeating the process. This is done to obtain precision in the readings. The whole process is then repeated for ethanol, chloroform and glycerin for five times each. Table 1 shows the values of voltages obtained in millivolts for different mediums and Fig. 5 shows the graphical representation of the obtained values.

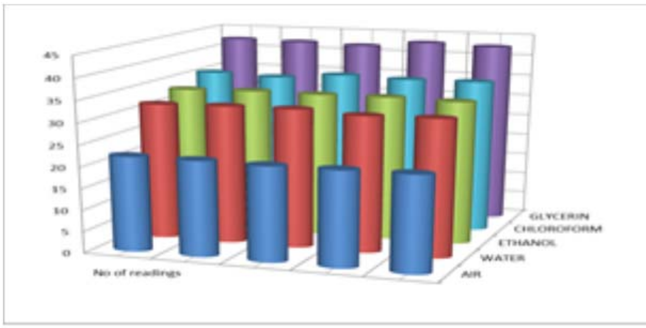

Fig. 5: Graphical representation of the obtained readings

Table 1: Experimental Values of the proposed system

Medium / No of readings	Air (RI= 1)	Water	Ethanol	Chloroform	Glycerin
1	22.2	31.9	33.4	35.7	42.5
2	22.2	32.2	33.7	35.2	42.3
3	22	32.3	33.6	36.3	41.9
4	22.1	31.6	33.7	35.9	43.1
5	22.2	31.8	33.4	36	42.7

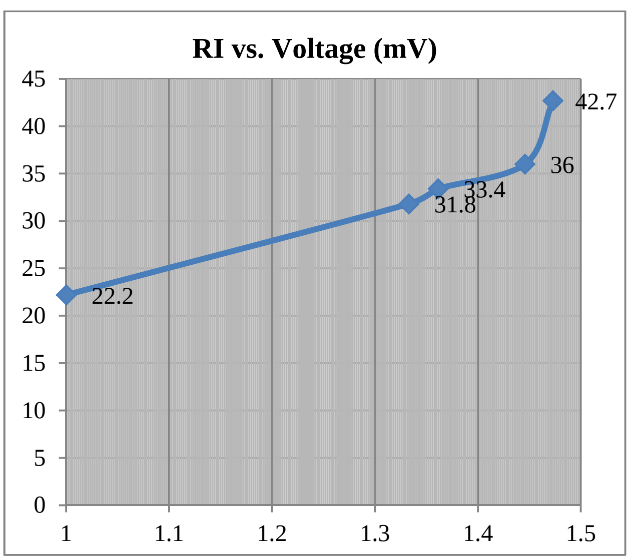

Fig. 6: Averaging curve of the readings

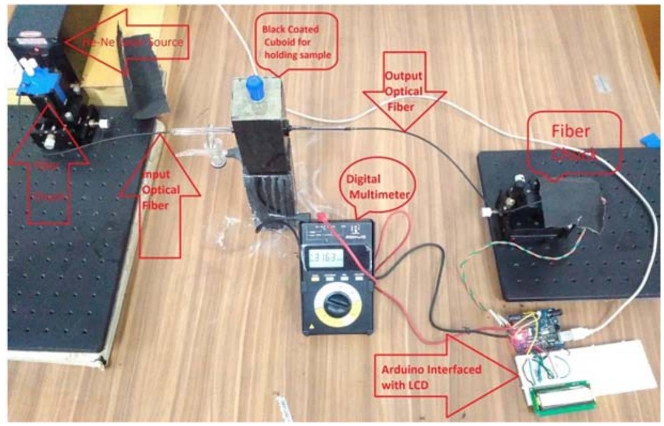

Fig. 7: Snapshot of the Experimental Setup

A curve shown in **Fig.** 6 has been obtained by putting these values in an excel sheet. The curve is found to be almost linear except for the value obtained for glycerin. This is may be due to high viscosity of glycerin. The detected output is again fed to an Arduino UNO board for displaying the refractive index of the solution in an LCD. To find the proper value of RI of the solution, a look-up table has been used in which RI is calibrated with voltage ranges based on the curve obtained from the experimental results. When a liquid is poured into the glass chamber, the refractive index of the liquid is displayed on the LCD.

5. CONCLUSION

An extrinsic method for detection of refractive index of colorless liquid based on intensity modulation is discussed in this paper. The system has been water, ethanol, chloroform and glycerin. A curve has been derived from the experimental values and a look-up table is formed from the results calibrating RI with voltages obtained at the detector. The output of the detector is further interfaced with LCD through Arduino board which processes the output voltage signal and converts it to the corresponding RI value.

6. ACKNOWLEDGEMENTS

This work was supported in part by Mr. Mathan Deka, Department of USIC and Instrumentation of Gauhati University, for fabrication of the glass chamber used in the system.

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