Conference Paper

Optical Fiber Polymer Sensor System with TiO_2-SiO_2 Cladding for Measuring Humidity

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Abstract
Optical fiber at range of 90.73% RH to 99.7% RH. The result shows that different levels are not far away, sensor system to detect air humidity using polymer optical fiber (POF) Autonics FD-620-10 has been developed. The POF sensor is performed by stripping cladding of the fiber and then replace it with TiO_2-SiO_2. The stripping variations are 1 cm, 2 cm, and 3 cm. The sensor system is composed of a red diode laser with wave length 638 nm as light source and photodiode light detector. The output from the detector will be displayed on an electronic viewer such as LCD or PC. Data processing is carried out using an ADC to get transfer function to be embedded into Arduino Uno. The obtained regression equation is y = 0.131x - 22.58 and the coefficient of determination (R^2) is 0.984. It is mean that the optical fiber sensor has a good linearity. The accuracy of the sensor is obtained from the comparison of the humidity gauge designed with a hygrometer (an existing humidity gauge). The error were generated by the designed device was 2.78%. The error results indicate that the percentage of errors from the designed device is relatively small, so it can be concluded that the humidity sensor can respond well to the measured humidity.

Keywords: humidity, laser diode, photodiode, Plastic fiber optic, TiO_2-SiO_2

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Received: 19 February 2019
Accepted: 5 March 2019
Published: 16 April 2019

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICBSA Conference Committee.

1. Introduction

Optical fiber is medium to carrying information from one point to another in the form of light. Different with copper transmission optical fibers are not electric. Fiber optic basic system consists of transmitting device that convert electrical signals into lightsignals, fiber-optic cables that carry light, and receivers that receive light signals and convert them back into electrical signals [1]. This optical fiber work using perfect reflection principle by utilizing the difference in refractive index between cores and cladding. Optical fiber can also be used as a sensor by combining the production of fiber optic telecommunications with optoelectronic devices to produce fiber optic sensors [2]. The sensor is the spearhead of a measurement system and control system. Sensor comes from the word sense which means to feel or sense a device (device) that receives signal or stimulus and responds the signal by converting it into electrical signals [3].

Sensors type that exist today are potentiometric, gravity, capacitive, pressure, distance, ultrasonic, magnetic, radar, humidity and optical sensors [3]. The humidity sensor of the air is interesting topic because its needs are critical for monitoring, detecting, and controlling surrounding humidity under a variety of conditions with precise and relatively less expensive sensors. The existing humidity sensor in the form of a hygrometer (humidity meter) or under development is relative humidity sensor (RH). Relative humidity sensors (RH) are categorized into three types namely ceramic (semiconductor), organic polymer-based sensors, and organic/ inorganic hybrid sensors (polymers/ ceramics). These three categories of sensors utilize physical properties and electrical properties change of sensitive elements under different atmospheric conditions [4]. The weakness of the existing humidity sensor demands sensor development to be more reliable. Polymer fiber optics (POF) is one of the ingredients for developing the need for humidity, pressure and temperature sensors [5]. POF has been used extensively in optical sensing applications, because of its flexibility, resistance to electromagnetic interference, resistance to effects caused by vibration, and good coupling of light from light sources [6]. The relatively simple preparation and fabrication process, making these polymer optical fibers provide the hope of creating an inexpensive humidity sensor.

Some researchers have conducted research on humidity sensors using optical fiber by replacing cladding fiber optic cables with materials that have hydrophilic properties. Zhang et al in 2008 tested the gelatin film response with a stripping length of 1.8 cm as a humidity sensor and it can respond to moisture from 42% RH to 99% RH with the best response moisture range are 60% RH to 72% RH [7]. Aneesh et al in 2009 characterized the silica type of fiber optic sensor with cladding modification using TiO_2 coating.The results showed that optical fibers with TiO_2 coating are in the dynamic range of 3.5% RH to 95.7% RH [8]. Recently in 2017 David ddk characterized the sensor using a fiber optic polymer with Allylamine Poly Hydrochloride (PAH) and Silica (SiO_2).The sensitivity obtained at relative humidity of 10% RH to 75% RH is about -3,87$\times 10^{-3}$ whereas at relative humidity of 90% RH to 97% RH is around -9,61$\times 10^{-3}$ [9]. Aneesh et al and David et al research will be updated by making air humidity sensor using polymer optical fiber (POF) type FD 620 10 coated TiO_2-SiO_2 instead of cladding.

The performance properties of the photocatalytic function of TiO_2 can be enhanced by the addition of SiO2 so-called Titania-Silica nanocomposites (TiO_2-SiO_2). The TiO_2 material is the base material as an amplifier and SiO_2 as the matrix so the SiO_2 doped matrix support can increase the area of TiO_2 [10]. Inter-particle bonding that occurs in composite-based materials plays an important role in the improvement and limitation of material properties. The mechanical properties of the material increase as a result of stronger interparticle bonds. TiO_2-SiO_2 is mixed oxide which has many applications in the catalyst field either as a catalyst itself or as a support catalyst. Composite particles make it possible to improve the catalyst properties of the photocatalyst.

Based on the sensitivity to be achieved in a humidity sensor, a relative humidity sensor that operates on the principle of intensity modulation was developed and demonstrated by Harith. Z et al in 2017 using a polymer optical fiber (POF) coated with Al-doped Nannostructured ZnO seeds. Sensors developed using superior coating methods show a better sensitivity of 0.0386 mV /% and compared with other sensors listed the sensitivity is 0.0148 mV /% [11]. The results of the study show that POF with Al-doped ZnO nanostructures uses excellent coating methods to detect changes in relative humidity.

The goal to be achieved is to produce a humidity measuring device using an optical fiber sensor system coated with TiO_2-SiO_2 as a substitute for cladding and the benefits produced are used as a humidity gauge. This humidity gauge is based on ATMega328 microcontroller using polymer optical fiber with cladding which replaced TiO_2-SiO_2 layer. The result of measurement in the form of analog signal will be converted into digital signal by arduino UNO in which there are microcontroller ATMega328 and ADC (Analog to Digital Converter) and then displayed on PC.

2. Materials and Methods

2.1. Materials research

Materials and tools that required for fiber optic cladding exfoliation are BF5R (optical fiber digital sensor), cutter knife, fiber optic cutting knife, acetone solution, and sandpaper. The optical fiber kebel is cut along 21 cm using a fiber-optic cutting knife, then the cord is peeled and immersed into the acetone solution slowly while rubbed with napkin tissue and then rubbed again repeatedly with sandpaper. Fiber optic of peeled cladding can be seen using BF5R. If the number that is indicated by BF5R far below 4000 that means the optical fiber cladding has been peeled off.

2.2. Preparation of TiO_2-SiO_2 coating

The preparation of TiO_2-$SiO_2$was performedpreviously using solid state method. It was continued by mixing 1 gram TiO_2 with 1 gram SiO_2, and adding 2 gram PEG 6000 andthen mixed together.Then it was crushed and heated until reaching 500°C for 2-4 hours. The heating process refers to the statement that anatase has phase that can be synthesized at temperature 400°C-500°C, while the rutile phase temperature are 500°C-600°C and brookite are 700°C [12]. Moreover, the solution preparation was carried out by taking 0.3 gram of the finished product, and put it into 30 ml aquabides, then stirred for 1 hour and further synchronized in order to minimize the particle size for 30 minutes.

2.3. Fiber optic coating with TiO_2-SiO_2

The coating process of the opticalfiber cable where its cladding had been peeled with TiO_2-SiO_2 was taken by using dip coating method. Prior to coating, the fiber was initially cross linked in citric acid solution as the binder agent between optical fibers with TiO_2-SiO_2. This process was conducted for 3 hours. The TiO_2-SiO_2coating on the sample was subjected to one immersion for 5 minutes. Then, the coated fiber was dried at 50°C for 15 minutes, so the fiber with TiO_2-SiO_2 cladding can be tested for humidity detection.

2.4. Measurement system

The measurement system used in this study is measuring relative humidity. The humidity sensor measurement system can be seen as Fig. 1.

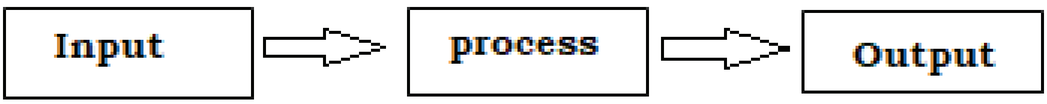

Figure 1: Measurement system.

Fig. 1 explains that the input part is also called a sensor element that serves to convert a physical quantity into another physical quantity. Parts of the process of performing data processing or signal provided by the input section to be modified in accordance with the quantity or signal required output devices. The output section of the task displays the information generated part of the process in a form in accordance with the needs of the system.

DOI 10.18502/keg.v1i2.4437

The measurement system in this study is humidity measurement system, which require data analysis technique to determine the level of accuracy and error in the measurement system. The percentage of errors can be determined by Equation (1).

$$e_n = \left| \frac{Y_{n-Y_o}}{Y_n} \right| \times 100\% \tag{1}$$

e_n is error percentage, Y_n is true value, and Y_o is value read on the measuring instrument. The percentage of measurement accuracy can be determined through Equation (2).

$$A_n = 1 - \left[\frac{Y_{n-Y_O}}{Y_n} \right] \times 100\% \tag{2}$$

2.5. Optical fiber sensor system

The mechanism of optical fiber sensor system is modulating light waves from a source like laser diode. Scheme of fiber optic sensor system as shown in Fig. 2.

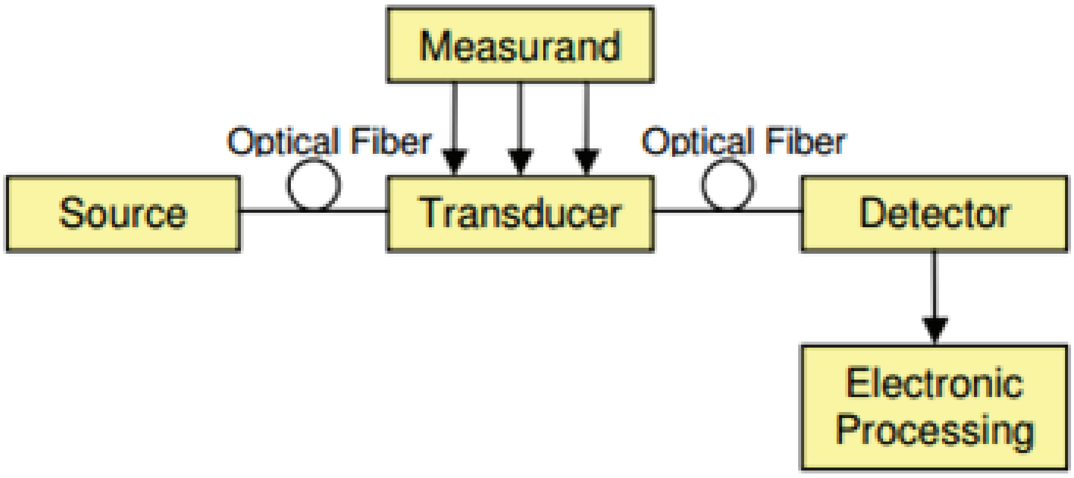

Figure 2: Schematic of fiber optic sensor system [13].

The light source transmitted at one end of the optical fiber to the transducer or the light modulation area then it forward to the other end of the optical fiber where there is a light detector. The output from the detector will be displayed through an electronic viewer such as LCD or PC. Based on the conditions of the modulation process, the optical fiber sensor system is distinguished over intrinsic sensors and extrinsic sensors, but in this study the sensor system used evanescent sensor system.

Evanescent sensors are sensors that guide light to the outer environment due to optical fiber cladding removal. If light is guided into the external environment, then there will be a loss due to the weakening of the intensity. This weakening effect of intensity is used to sensing the external environment. Cladding can be removed so that the core directly interacts with the external environment and automatically refractive index function of cladding is replaced by air refractive index [10]. The evanescent field can be written as in equation (3).

$$E_z = E_0 Exp\left[-\frac{z}{d_p}\right] \tag{3}$$

Where z is the distance of the light wave (distance from the boundary area of the core and the cladding), $E_0$is the initial wave field, and d_p is the penetration depth. Penetration depth is the depth of the wave entering the cladding. It can be formulated equation (4).

$$d_p = \frac{\lambda}{\frac{2\pi}{n}\sqrt{\sin^2\theta - n^2}} \tag{4}$$

Where n is the cladding index ratio to the core ie n cladding versus n cores. The above equation explains that the evanescent wave penetration depth depends on the refractive index value of cladding relative to the core refractive index. The deeper the penetration of the evanescent wave the smaller the intensity of the guided light in through the optical fiber.

2.6. Design of humidity measurement system

The humidity measurement system used optical fiber sensor system with evanescent method. Optical fibers visualize thing by modifying optical fiber cladding by case peeling the original optical fiber cladding and coating it with TiO_2-SiO_2 instead of cladding it. Generally overall system block diagram can be seen in Fig. 3.

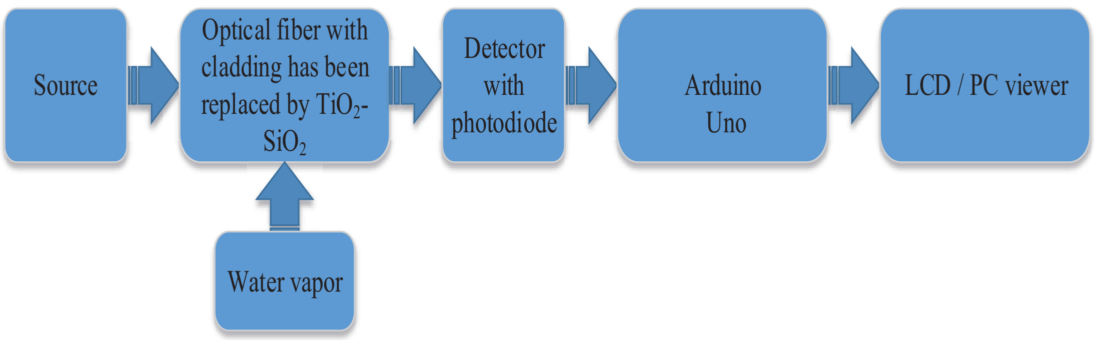

Figure 3: Block diagram of humidity measurement system.

The block diagram of the entire optical fiber sensor system for moisture measurement can be seen in Fig. 3. Cladding of the fiber optic cable is peeled using a cutter, then coated with TiO_2-SiO_2 and inserted into a box called humidity chamber. The optical fiber is illuminated by a light source, the laser diode. The light that propagates in the optical fiber will be detected by the photodiode, resulting in an output value. The output value of the photodiode is the voltage sent to the arduino Uno microcontroller and the decimal shape is changed by the internal ADC. Data will be processed by Arduino Uno microcontroller according to the designed program. Data transmission is done using an ethernet shield connected to the internet. Relative humidity results can be displayed on the LCD/ PC.

3. Results and Discussion

3.1. Characterization of relative humidity to voltage

The characterization of optical fibers can also be seen through the linearity and sensor hysteresis curves. The data is taken by looking at the output voltage graph against the humidity of the air when the humidity value rises and the humidity falls. Humidity is regulated by draining moisture to a preheated humidity chumber.

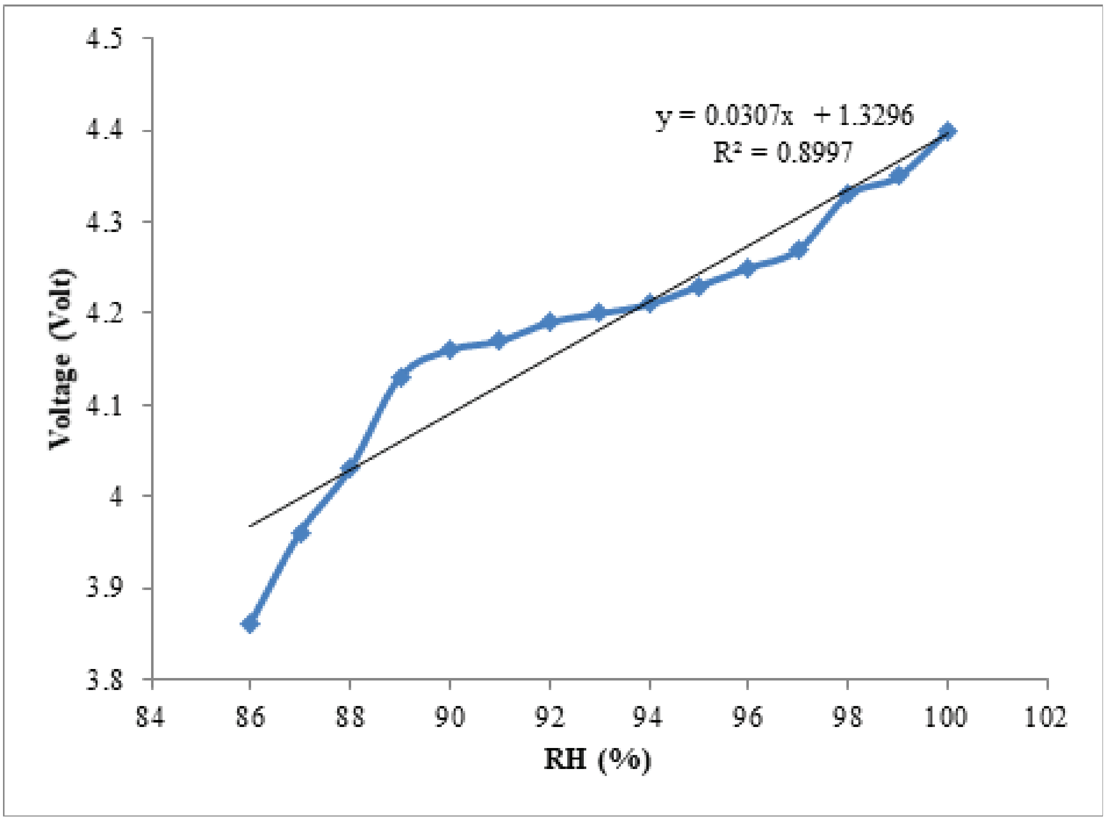

Figure 4: The relation of humidity to Voltage at stripping length 1 cm.

Fiber optic sensors which have the most optimum or best linearity and hysteresis curves from Fig. 4 to Fig. 6 will be used on the measuring device. Fig. 5 shows the characterization of the fiber optic sensor linearity having the most accurate correlation

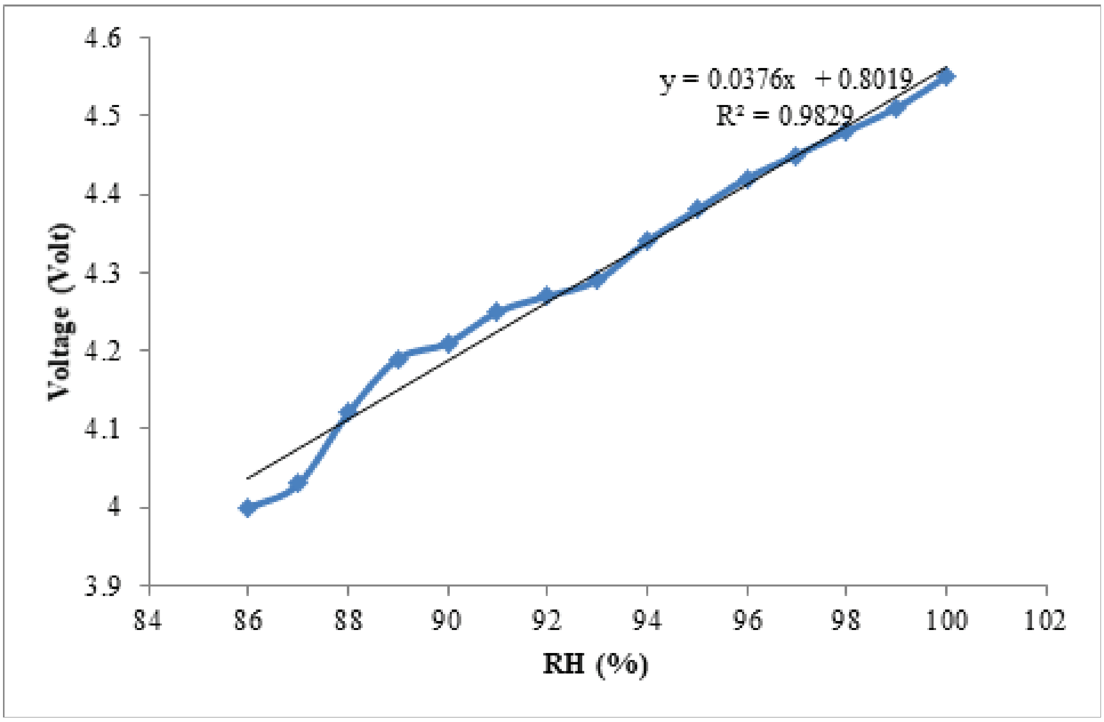

Figure 5: The relation of humidity to Voltage at stripping length 2 cm.

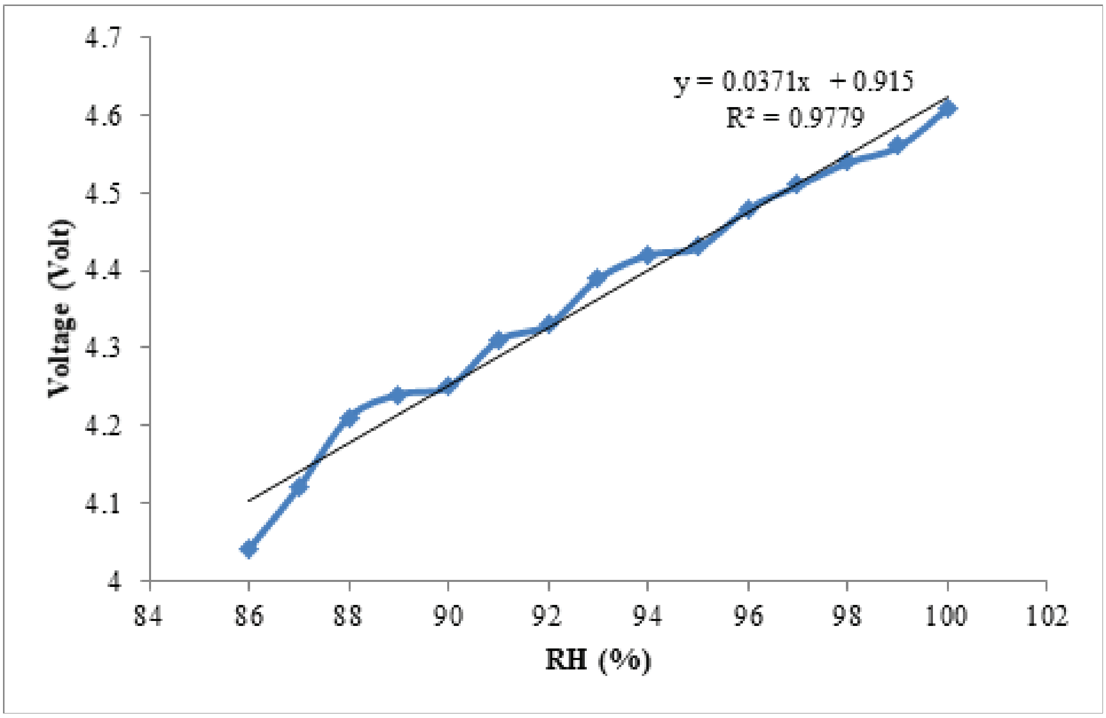

Figure 6: The relation of humidity to Voltage at stripping length 3 cm.

degree existed on the optical fiber with a stripping length of 2 cm with a TiO_2-SiO_2 coating with a ratio of 1:2 representing R^2 = 0.982 with the most optimum sensitivity of 0.0376 V/%.The result states that the higher the air humidity the higher the voltage generated by the photodiode output. This is due to the smaller intensity of light traveling on optical fibers [14] and this is also in line with Zhang et al's research which states that the higher the air humidity, the smaller the optical fiber output power produced [7]. Sensitivity obtained from polymeric optical fiber coated with TiO_2-SiO_2 in accordance with the reference of research conducted by Harith. Z et al [11].

The smaller light intensity is caused by evanescent waves that penetrate the deeper cladding, because as the humidity rises, the TiO_2-SiO_2 laipsan decreases. Based on equation (1) if the index density of cladding bias is smaller then the depth of penetration deph (dp) of the evanescent wave is smaller. The results obtained are in line with Zhang et al with a stripping length of 1.8 cm [7].

3.2. Characterization of relative humidity to ADC

Characterization of the relation between humidity and ADC is done to obtain transfer function that used in this research. That transfer function is planted in Arduino UNO module to get the measurement of air humidity. The graph of humidity characterization of ADC can be seen in Fig. 7.

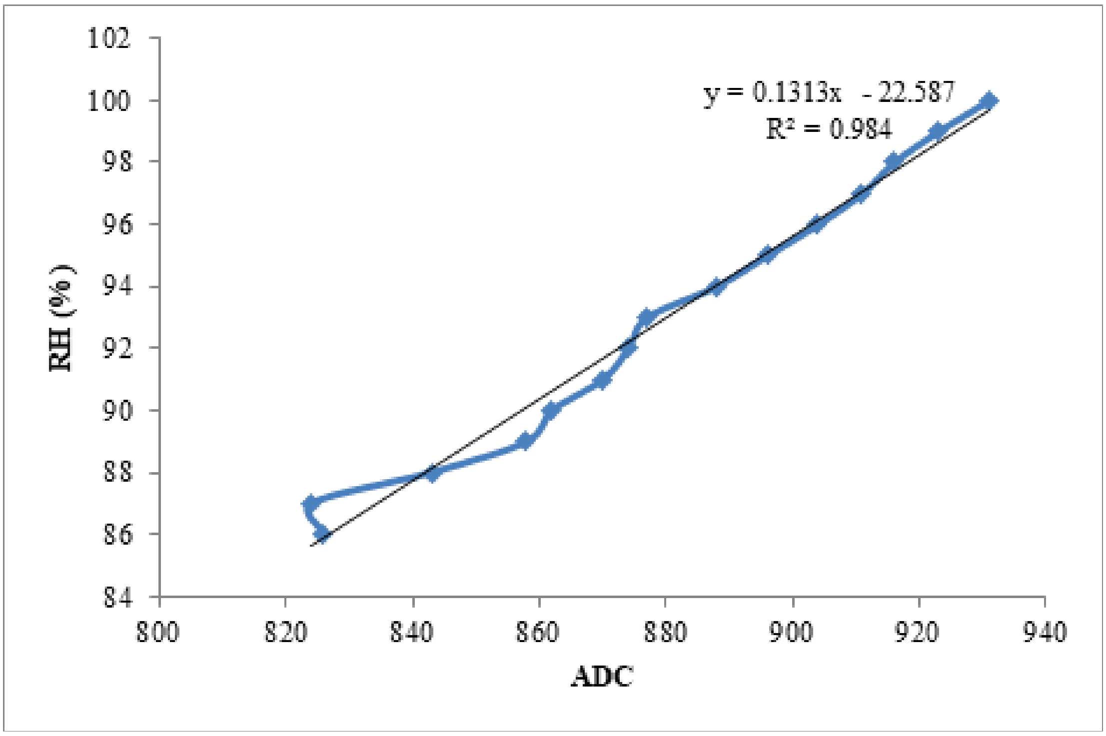

Figure 7: The relation of humidity to ADC at stripping length 2 cm.

The data from Fig.7 is taken at the best peel length, 2 cm with the obtained equation y=0.131x - 22.58, where x is the ADC input voltage of the photodiode output and y is the ADC value which is the measured humidity value of the air. The value of 0.131 is the magnitude of the ADC conversion factor, whereas -22.58 is the offset voltage of the ADC. The correlation coefficient (R^2) obtained is 0.984. It means that measured optical fiber has pretty good linearity.

3.3. Humidity measurement test

The final test of this moisture meter is sensor readings result.It is useful to see how accurate the accuracy level of the measuring instrument is made to detect the humidity of the air compared to the result of the humidity meter [14]. Images and test results and measurement of measuring instruments can be seen in Table 1.

Table 1: Comparison of measuring instruments made with humidity meter.

No.	Humudity measuring instrument designed (%)	Humudity with hygrometer (%)	Error (%)
1.	88,8	90,73	2,2
2.	89,7	91,27	1,7
3.	92,04	95,8	4,1
4.	95,19	98,6	3,6
5.	97,42	99,7	2,3
Rata-rata error			2,78

The average error obtained from the processing of the formula in equation 1 shows the discrepancy between the readings of the device designed with the standard gauge. Many factors cause this because the designed sensors are still very susceptible to systematic errors. However if it is viewed from the air humidity graph of the output voltage and the ADC, the designed optical fiber sensor has shown a linear response to the air humidity.

Photodiode close to the optical fiber end is still done manually, it can change the output voltage and ADC value when done several repetitions. Bending changes occurring in micro and macro scale affect the spreading of light within the optical fiber. The evanescent optical fiber sensor with the substitute of TiO_2-SiO_2 cladding has responded to the air humidity well, but it has not been able to be used as a sensor for the design of the measuring instrument because there must be standard and fabrication tested to make the sensor more stable. This evanescent optical fiber sensor can be used as a reference to improve the ability to respond to air humidity sensors with better cladding replacement materials in absorbing water (moisture).

4. Conclusions

The polymer fiber optic sensor system with Tio2-Sio2 cladding has been able to respond to air humidity with the most optimum length of stripping cladding obtained at 2 cm stripping length. it can be seen from the coefficient of determination that is R2 = 0.982 the most optimum sensitivity is 0.0376 V /%. The accuracy of the accuracy of the measuring instrument designed to detect air humidity by comparing the results of the hygrometer, the error obtained is 2.78%, where the humidity of the measuring instrument designed is in the range 88.8% RH to 97.42% RH and humidity the air from the hygrometer is in the range of 90.73% RH to 99.7% RH.

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