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Characterization of Multiple-bend Optical Fiber Extensometer Design for Landslide Sensor

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ABSTRACT

Design of multiple-bend extensometer based on optical fiber as landslide sensor has been characterized. Multiple-bending characterization has been done by varying the winding number of optical fiber FD-620-10 to obtain the photodiode's effective light intensity. The light intensity in the extensometer was set by varying the laser diode resistance in the range (150 – 250) Ω. The optimum sensitivity of 0.03984 V/cm was obtained for triple winding of optical fiber. The designed optical extensometer is able to monitor the displacement with an error of 0.59%. This result indicates that the designed extensometer is the more bending on optical fiber, the more its sensitivity and the bending loss.

1. INTRODUCTION

Extensometer is a device that can be used to detect the magnitude of displacement. In the application, most extensometers are used to monitor land displacement (Jawwad, 2015). There are two types of extensometer such as wireline extensometer and an optical extensometer. A wireline extensometer is an electrical extensometer that can monitor the landslide by utilizing the frequency of the vibrated wire. An example of a wireline extensometer is Linear Variable Differential Transformer (LVDT) sensor. LVDT sensor utilizes an electromagnetic transducer that converts the object motion mechanically into a suitable electric signal (Priyanto, 2015). The wireline extensometer suffers from electrical interface noise that may damage the extensometer.

The optical extensometer is a device to measure an object's displacement in the horizontal axis based on light transmission (Zhou, 2007). Most optical extensometers use optical fiber as a landslide sensor. Optical fiber is used in many fields such as industrial manufacturing, geophysics survey, and disaster mitigation (Rajan, 2015). Optical fiber is made from insulator material that can guide the light without absorbing it and minimize it due to electromagnetic interference. The principle of the sensor is measuring the intensity change of light propagating in the optical fiber. Bending loss of optical fiber will change in the course of the landslide (Waluyo, 2010).

Optical extensometer manufacturing evolution continues until these days, which is indicated by a variety of published studies. Bayuwati (2010) made the optical extensometer with Fujikura optical fiber. The sensor was formed from a piece of bend optical fiber. This optical fiber sensor is based on macrobending and classified into an intrinsic sensor, where the physical property of the optical fiber itself changes due to the environmental effect. The sensor can detect the displacement with an interval (0 – 25) mm with a sensitivity of 0.015 V/m.

Macrobending is a macro-scale bending producing bending loss in optical fiber where the optical loss caught by the light detector catches will increase, and the measured intensity of light will decrease (Waluyo, 2009; Wang, 2005; Wang, 2009). The bending losses of optical fiber for communication systems must be avoided or minimalized. However, for the optical fiber system, these bending losses are crucial for sensor operation. Waluyo (2009) has characterized the bending losses of optical fiber with Optical Time Domain Reflectometer (OTDR). This characterization was done using two types of optical fiber wrapped around the windings and the diameter variation of optical fiber bending. The result showed that the type of optical fiber telecommunication grade with one until two millimeters of turn diameter is more sensitive than sensor grade with (5 – 8.5) mm of a diameter of windings. The result of characterization will be used for the development of optical fiber design.

Herlin (2020) made a landslide sensor using optical fiber-based on the Internet of Things (IoT). The designed optical fiber sensor has one turn where windings diameter changes when optical fiber gets pulled. The characterization showed that the regression coefficient's value was 0.915 with output voltage between (1.8 – 3.3) V and 1.53 % error. An additional number of optical fiber windings is required to reach the maximum output voltage and power loss.

The development of research about the bending of optical fiber is limited to single bending, and some research has applied to multiple bending (Kuang et al., 2010). The multiple bending modeling can extend the interval of displacement and sensor sensitivity (Babchenko, 2007). According to Faizah (2012), the optical extensometer with heart multiple bending has an operating principle where the optical fiber bending surface pressure represents the displacement. The method is used by giving multiple bending for optical fiber. This displacement will affect the optical fiber pressed until formed into three dynamic windings with heart form bending.

This work reports that the optical extensometer has been designed and characterized using optical fiber with several winding variations. The benefit of this variation is to increase the sensitivity and bending loss of optical fiber sensors. The result of the designed sensor will be compared with the comparing instrument to observe the designed sensor's efficiency.

2. METHOD

2.1 Tools and Materials

The tool used for characterization were luxmeter and multimeter. The extensometer component was optical fiber step-index multimode FD-620-10, photodiode, laser diode, Arduino Uno, and potentiometer.

2.2 Characterization of Laser Diode and Photodiode

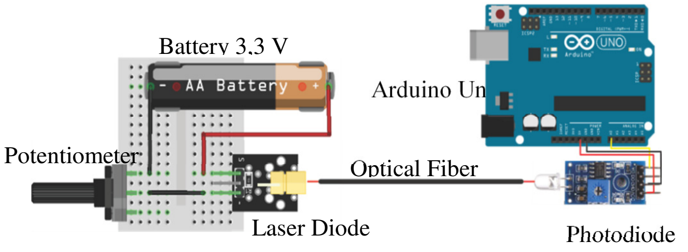
The characterization of laser diode and photodiode was conducted to determine how much light intensity from laser diode was converted into photodiode voltage. The intensity of light was measured using a luxmeter. A potentiometer was used to regulate the light intensity emitted from a laser diode.

The potentiometer resistance was varied between (0-1) kΩ with a 50 Ω of resistance range to control the light intensity from the laser diode. The characterization scheme is showed in Figure 1.

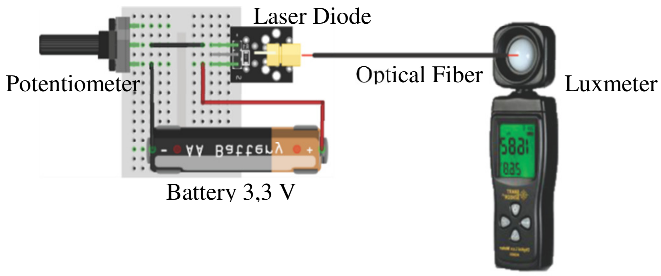
2.3 Characterization Number of Optical fiber Winding with Output Voltage

This characterization was performed to find the maximum voltage and sensitivity of optical fiber bending. The optical fiber used was type FD-620-10 step-index multimode that changed into a single-mode. The laser diode emits light with a 1550 nm wavelength and exponentially responds upon macrobending (Jay, 2010). The characterization with an amount of optical fiber bending used the multiple bending that causes vertical macrobending. The components used in this characterization are arranged in series in a specifically designed acrylic box.

The variation of the number of optical fiber windings was one to three windings with a diameter of 10 cm. Optical fiber diameter is also the maximum displacement length from the sensor. Each one centimeter of displacement from optical fiber bending will produce a different output voltage. The scheme of characterization showed in Figure 2.



(a)



(b)

Figure 1. Characterization scheme of resistance variation from a potentiometer as light source setting of laser diode toward (a) voltage of photodiode (b) light intensity measured with luxmeter.

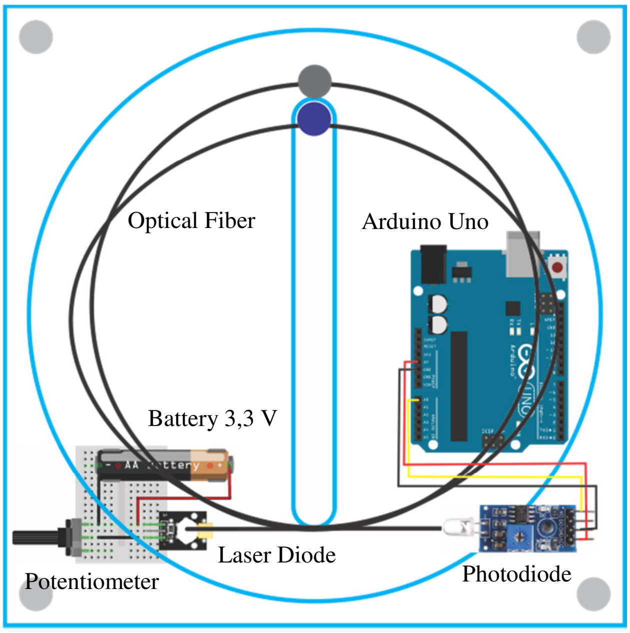


Figure 2. Scheme of characterization number of optical fiber windings toward voltage.

2.4 Data Analysis

Data analysis is a process to find out the accuracy of the measurement system. The accuracy is the suitability level of measurement result toward the correct value. The system's accuracy is determined from the error percentage between the correct value with the measurement value. The error percentage of measuring instrument determined with Equation (1)

$$e_n = \left| \frac{Y_n - X_n}{Y_n} \right| \times 100\% \,. \quad (1)$$

Y_n is the correct value of the comparison instrument, and X_n is the measured value of the measuring instrument. Deviation standard of the measuring result of measuring instrument determined using Equation (2).

$$S_n = \sqrt{\frac{\sum(e_n - \bar{e})^2}{n(n-1)}} \ . \tag{2}$$

Sn is the deviation standard, *e* is error percentage, $\bar{e}$ is the average error percentage, and *n* is the number of data from measuring the results. The comparison instrument used was a crossbar.

3. RESULTS AND DISCUSSION

3.1 Effect of Potentiometer Resistance

The laser diode's light intensity has changed due to the variation of transformation resistance measured by the photodiode to result in output voltage. The result of the resistance variation experiment of laser diode with light intensity and output voltage from photodiode showed in Figure 3.

The increase of resistance value of laser diode reduced light intensity measured by luxmeter. The light emitted by the laser diode becomes dimer with the increase of potentiometer resistance. This characterization was performed to determine the value of light intensity that should be regulated on the laser diode's potentiometer.

The output voltage produced from the photodiode decrease with the increase of the resistance value of the laser diode. This is caused by the voltage divider circuit in the photodiode module using operating mode where the more light intensity, the less output voltage. This characterization was performed to find the maximum voltage produced from the photodiode when the light was emitted from the laser diode.

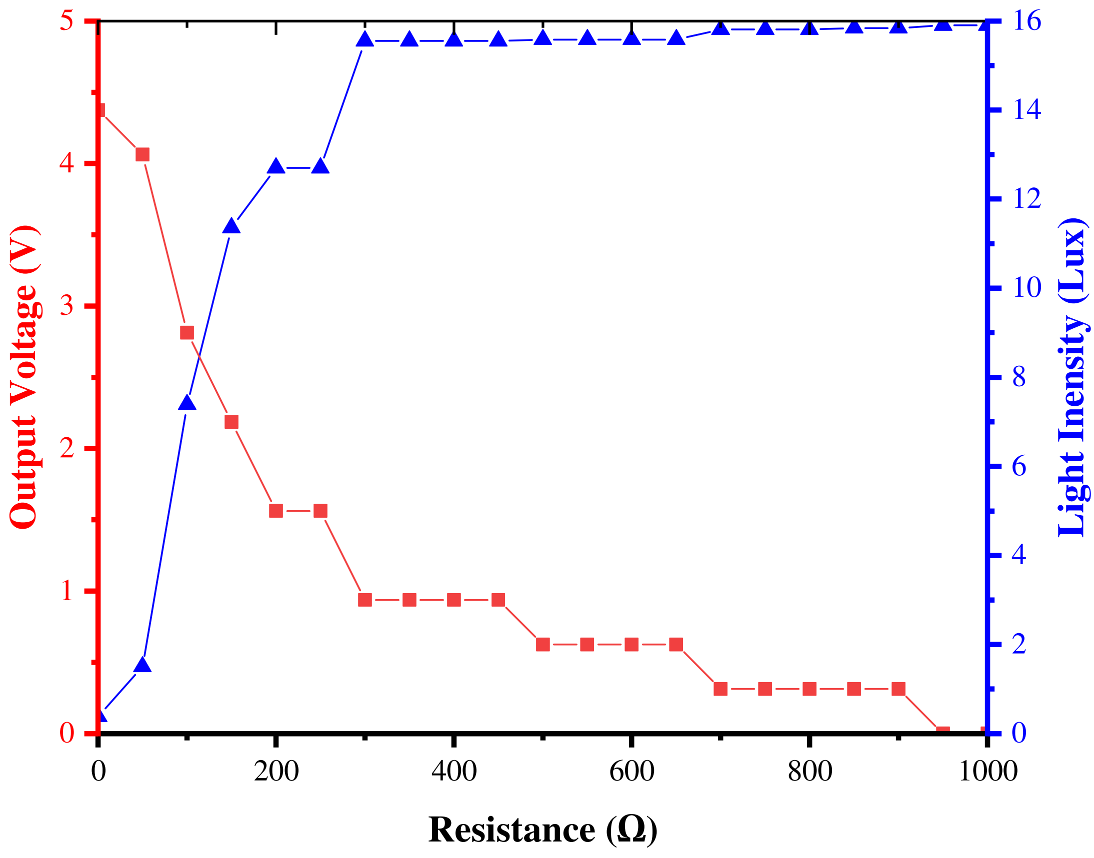


Figure 3. The graph of the effect of resistance variation of laser diode toward light intensity and output voltage

The variation of laser diode resistance with light intensity and output voltage from photodiode was also performed to determine how large the resistance is appropriate for laser diode and captured by the photodiode. The resistance of (150 – 250) Ω can be used for laser diode as a light source for optical fiber sensors. The resistance (300 – 1000) Ω produces the output voltage of almost 5V and results in zero photodiode response when the bending of optical fiber changes. The elevated light intensity causes this made the photodiode's output voltage turned lower and can not respond when the optical fiber is bent. Arduino as a signal processor can not respond because the output voltage was too low.

3.2 The Effect of Number of Fiber Windings

Several optical fibers winding experiments with output voltage were conducted to get the photodiode's maximum voltage. Windings were varied from one to three with a bending diameter of 10 cm. The number of three windings was the maximum number where fiber optic can be bent. This is because the optical fiber length was 1.5 m if the circumference of bending was counted and added with several centimeters installed to laser diode as light source and photodiode as detector derived, three windings as the most windings. The result of several windings optical fiber with output voltage from photodiode showed in Figure 4.

Figure 4 shows the effect of optical fiber's winding variation experiment on the photodiode's output voltage. The multiple-bending transformation in every variation of windings number produced a different output voltage change when the optical fiber gets pulled. The larger the displacement when the optical fiber is pulled, the higher the output voltage. The increase of output voltage is caused by decreased bending losses in vertical macrobending optical fiber. The photodiode's lower light causes the increase of bending losses until the output voltage increases.

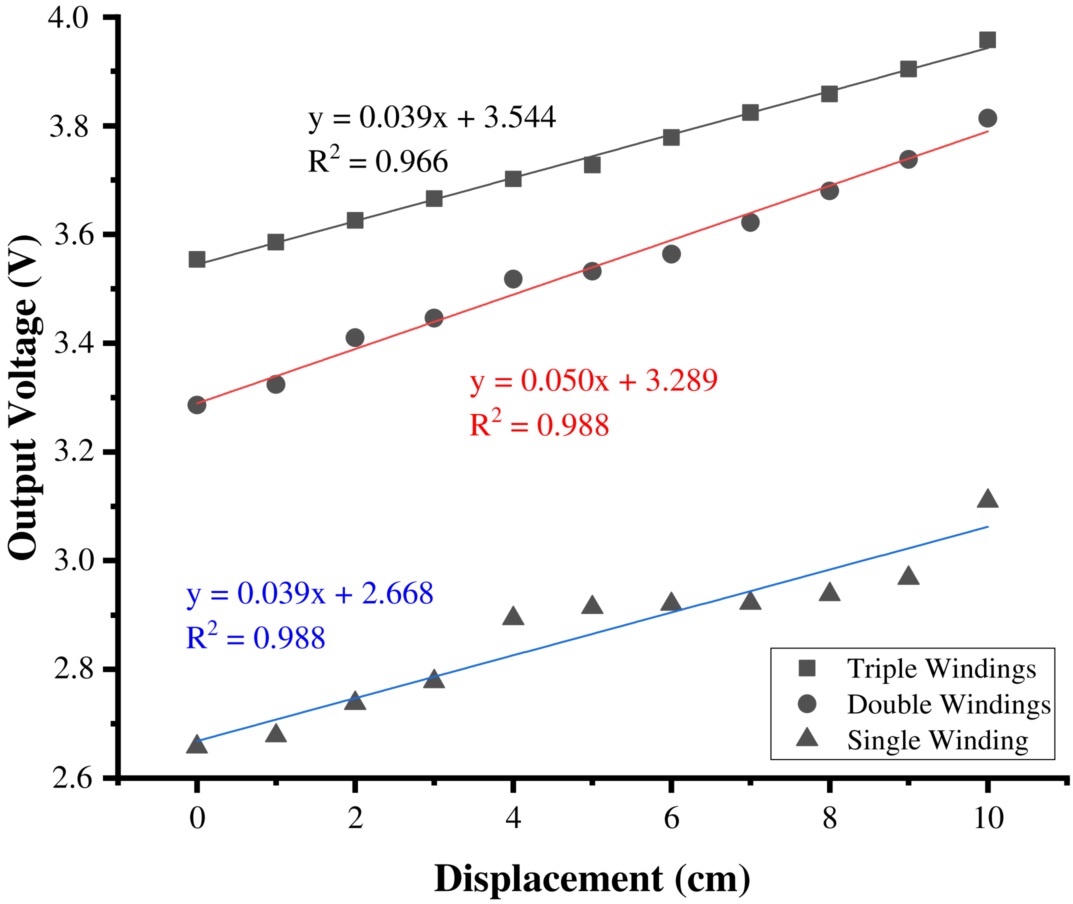


Figure 4. The graph of the effect of windings number variation of optical fiber with output voltage

The number of windings variation that produced the highest output voltage was optical fiber with three windings. This is due to the rising number of windings that caused bending losses of optical fiber getting increase so that the output voltage in every displacement also increased. Optical fiber with three windings has the largest regression coefficient, which is 0.9964 with a sensitivity of 0.03984 V/cm. Nevertheless, Herlin (2020) only uses single winding where the bending diameter was 10 cm with regression coefficient was 0.915 and sensitivity of -150.3 V/cm, and Bayuwati (2010) with the experiment result was 0.015 V/cm of sensitivity with (0-2.5) cm of bending diameter. In this result experiment, three windings optical fiber's sensitivity value informed that every alteration of displacement as far as one centimeter will be converted into the voltage as 0.03984 V.

3.3 The Calibration of Optical fiber Sensor as the Landslide Sensor

This experiment was done to determine the accuracy of the designed system. In the previous experiment laser diode with 150 Ω of resistance and triple windings was used as the optical fiber for the displacement sensor. Length of displacement measured by optical fiber suitable with the radius of optical fiber bending was ten centimeters with a one-centimeter interval for each displacement.

Figure 5 showed the orange line was the comparison instrument value, and the blue line was the optical fiber sensor value. The trend between the two curves has the same linear slopes. The experiment result showed that the average error was 0.59 % with a 0.175 deviation standard. Based on the data from Figure 5 can be concluded that optical fiber sensor can operate adequately.

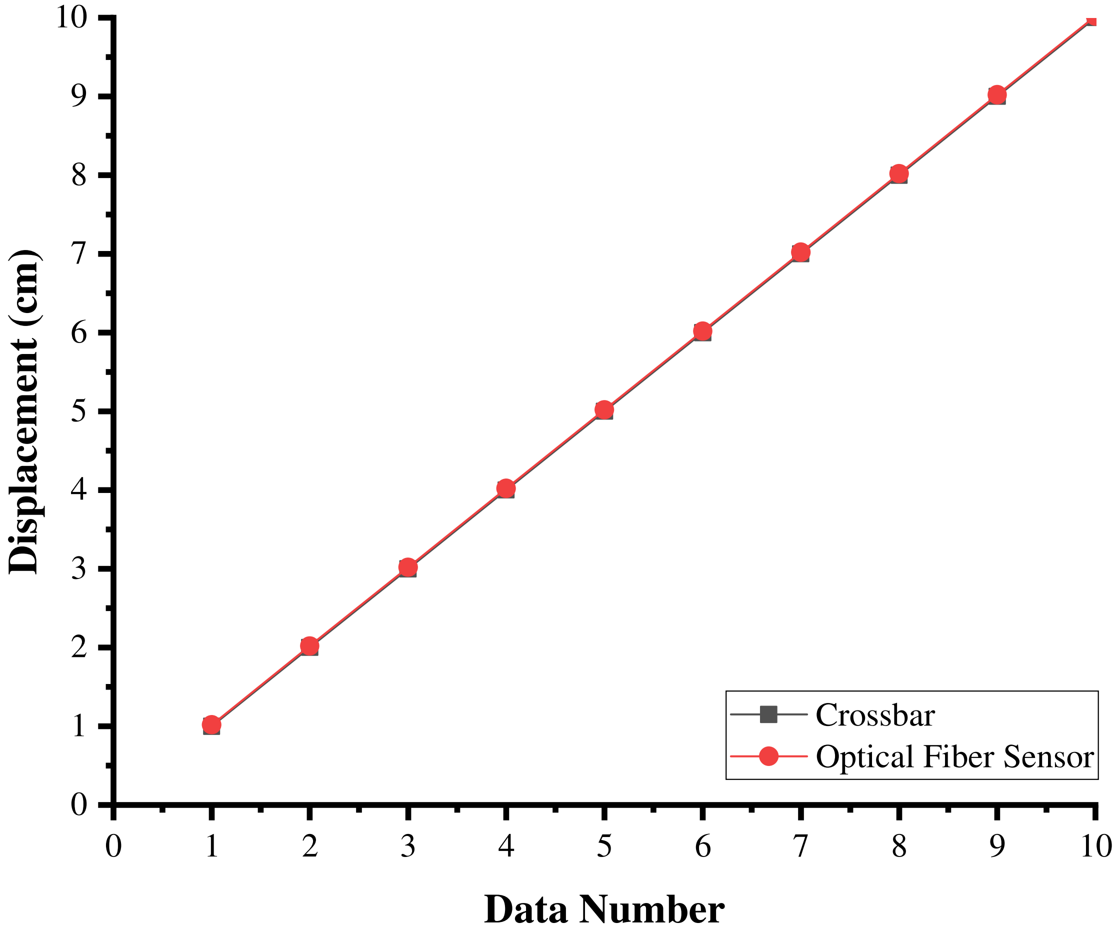


Figure 5. The graph of displacement value comparison between the crossbar and optical fiber sensor

4. CONCLUSION

Characterization of resistance variation potentiometer to adjust the light intensity of laser diode showed that the (150-250) Ω was the resistance that can be used for optical extensometer. Laser diode with (150-250) Ω of resistance has 11-13 lux of light intensity. The more resistance value regulated, the more light intensity and the less the output voltage. The number of windings variation of optical fiber to output voltage showed that the triple-windings of optical fiber derived the optimal voltage for optical extensometer with 0.03984 V/cm of sensitivity and R^2=0.9964 of regression value. Based on the characterization that has been done, the optical extensometer design can monitor the displacement with a 0.59 % error compared to the crossbar as a comparison instrument.

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