

Enhancing Landslide Early Warning: Advances in Fiber Optic Sensor Sensitivity

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Abstract

Fiber optic sensors offer a high-performance alternative because of a low-cost solution, resistance to electromagnetic interference, multiplexing capabilities, and high integration. This study aims to determine the optimal value of optical fiber types in landslide early detection sensors. The method used is bending in the form of deflection on the optical fiber. The deflection values used are 0 mm - 15 mm, 0 mm - 20 mm, and 0 mm - 25 mm. The optical fiber is placed horizontally in the middle of the bending tool. This bending affects the deflection of the optical fiber, resulting in the attenuation of light in the optical fiber. The deflection phenomenon results in light attenuation in the optical fiber. A single-mode fiber optic sensor's sensitivity level is higher than a multimode's. It shows the greater linearity value in each deflection treatment. Single-mode optical fiber linearity data on deflection variations of 0 - 15 mm, 0 - 20 mm, and 0 - 25 mm, respectively, are 0.9833, 0.9871, and 0.9847. At the same time, the linearity data of multimode optical fiber is 0.8926, 0.9841, and 0.9687. Single-mode optical fiber is more sensitive than multimode optical fiber. It is caused by the core diameter of single-mode optical fiber, which is much smaller than that of multimode optical fiber. The difference in core diameter results in differences in light propagation in the optical fiber. The small diameter of the core has a low dispersion level so that more light intensity is reflected into the core. Light attenuation occurs in a single-mode optical fiber due to macrobending treatment. Meanwhile, the attenuation of light in Multimode fiber optics is due to the bending and dispersion of light. Therefore, a landslide early detection sensor design is more optimal when using a single-mode optical fiber.

Keywords: optical fiber; macrobending; sensor; deflection; landslide

INTRODUCTION

Indonesia is a tropical country that has two seasons: the dry season and the rainy season. Natural disasters during the dry season include droughts, forest fires, and the death of many species of flora and fauna due to a lack of water.

Meanwhile, the rainy season is prone to floods and landslides. Therefore, the Indonesian people must be alert to natural disasters in their country. Disaster preparedness must be prepared early to minimize losses [1].

Predicting disasters as early as possible is done to prevent or reduce the impact of natural disasters on society. When it is too late to deal with disasters, there is a huge loss to the community. Disaster management can be pursued through a system that can provide early information about the signs of natural disasters. Providing early information can alert the community to natural disasters. The series of systems used to provide this information is an early warning system. Therefore, the community needs the system to reduce the impact of disaster losses [2].

Examples of early disaster detection system applications are flood and landslide detection. Floods can be detected using the Internet of Things (IoT) approach. The working principle of this system is remote monitoring technology that utilizes the internet as a link. Flood detection uses a Water Level Sensor and NodeMCU ESP8266 to measure the water level, and the data reading is displayed on the smartphone screen [3]. Early detection of landslides can be done by measuring the physical quantities that cause landslides, namely water content, ground surface displacement, and soil strain. In addition, data can be read and transmitted from the location to the monitoring station using a sensing system (sensor) [4].

Landslide monitoring techniques have traditionally used extensometers [5]. However, these sensors are easily damaged by lightning and electromagnetic interference. Over the past few years, the invention of optical fiber has addressed the shortcomings of extensometers. Optical fibers were developed into sensing systems (sensors). This sensor works by detecting changes in light transmission due to the bending of the optical fiber when there is a ground shift [6]. The advantages of optical fiber sensors are resistance to electromagnetic interference, multiplexing, small size, wide frequency, and high sensitivity [7], [8].

Most landslide sensors use multimode optical fiber because it is more affordable than single-mode optical fiber. This research uses both types of optical fiber to determine the optimal value of each optical fiber for the early detection of landslides using fiber optic sensors. This sensor is used because the data transmission uses the speed of light, which is 3×10^8 m/s, so it is faster in conveying information to the disaster response monitoring station. The faster and more accurately the sensor conveys information, the higher the sensitivity. The existence of this landslide early detection sensor is expected to reduce or prevent the occurrence of disaster impacts on the community.

This study focuses on enhancing the sensitivity of fiber optic sensors for landslide early warning systems by analyzing the impact of macrobending on

light attenuation. By comparing the performance of single-mode and multimode optical fibers, this research aims to determine the most effective fiber type for detecting soil displacement with high accuracy. Given the crucial role of early warning systems in disaster mitigation, optimizing fiber optic sensor technology can significantly improve response time and minimize potential losses caused by landslides. The findings of this study are expected to contribute to the development of more reliable and efficient landslide monitoring systems, ultimately aiding in disaster preparedness and risk reduction efforts.

METHODS

This research refers to the Standard Test Method (STM) C-770, which contains the Standard Test Method for Macrobending Measurement - Optical Coefficient. The tools used are a laser diode, a fiber coupler, a connector, a photodiode, and a set of optical bending tools. Meanwhile, the materials used are single-mode and multimode optical fibers.

Optical fiber transmittance is the ratio between the light intensity of the reference optical fiber and the modulation. The light intensity is converted into a digital signal as a voltage through an analog-to-digital converter (ADC). The optical fiber transmittance equation is:

$$T = \frac{V_2}{V_1} \quad (1)$$

where T is transmittance, V_1 is the voltage in reference optical fiber, and V_2 is the voltage in modulated optical fiber.

The experimental procedure employed in this research, as illustrated in Figure 1, provides guidelines for measuring changes in optical power in fiber optic systems under various physical conditions. In this study, a coherent light source (laser) is launched into a fiber optic system composed of two parallel optical fibers: one serving as a reference channel (FO reference) and the other as a test subject (FO modulation). The optical signal is split equally using a 50:50 fiber optic coupler, ensuring that the reference and test fibers receive identical input power. These fibers are connected to a photodiode system through standard fiber optic connectors, which ensures low-loss coupling and stable alignment. The reference fiber remains in its default state without mechanical interference, while the test fiber is subjected to controlled macrobending to simulate strain conditions relevant to landslide detection scenarios.

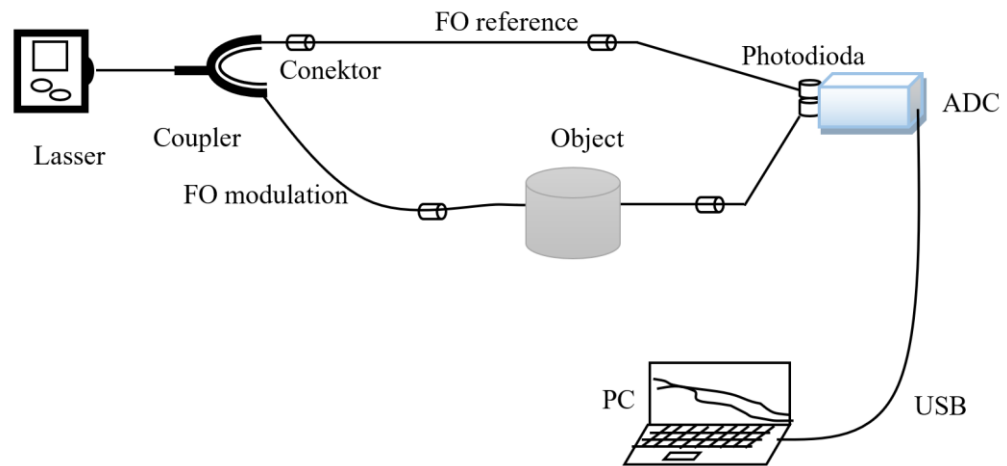


Figure 1. Schematic of the research to increase the Fiber Optic Based Landslide Early Detection Sensor sensitivity

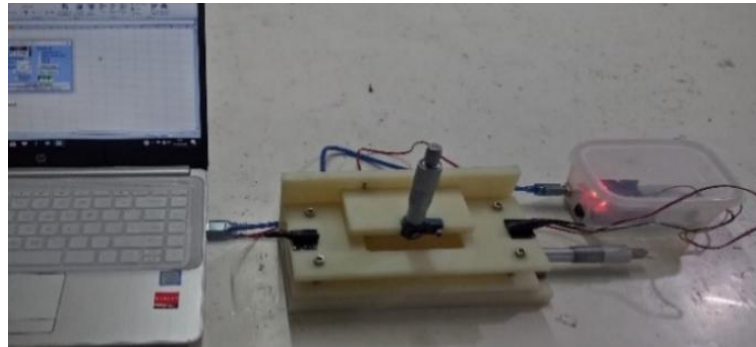
To ensure measurement accuracy, the system undergoes initial calibration. During calibration, the reference and the modulated optical fibers are kept straight and free from bending stress. In this neutral state, the photodiode should detect equal light intensity from both paths, verifying the symmetrical split and integrity of the optical components. The photodiode converts the received light signal into electrical signals fed into an Analog-to-Digital Converter (ADC). The ADC then digitizes these signals for further processing. The digitized outputs are transmitted via USB to a personal computer (PC), where the signal intensity can be monitored in real-time. This setup enables high-resolution detection of signal changes due to environmental disturbances or structural deformations in the test fiber.

After calibration, systematic testing is performed by inducing macrobending on both single-mode and multimode optical fibers. The bending radius, angle, and location are varied to observe how each type of fiber responds to mechanical strain. As per the STM C-770 standard, optical signal attenuation increases with bending, which is recorded as a reduction in light intensity detected by the photodiode. The difference between the reference and modulated signals provides a quantitative measure of strain sensitivity. This allows researchers to evaluate which fiber type and configuration perform best for landslide early detection systems. This method ensures precise monitoring of physical deformation and enhances the robustness and responsiveness of the early warning infrastructure using fiber optic technology.

RESULT AND DISCUSSION

This research used a macrobending system on single-mode and multimode optical fibers. The bending of the optical fiber comes from the macrobending given by the bending tool set. The set of bending tools can be seen in Figure 2. The macrobending directly hits the optical fiber. This causes

the optical fiber to bend so that the transmitted light decreases. The decrease in light transmission increases light attenuation on the optical fiber.



(a)



(b)

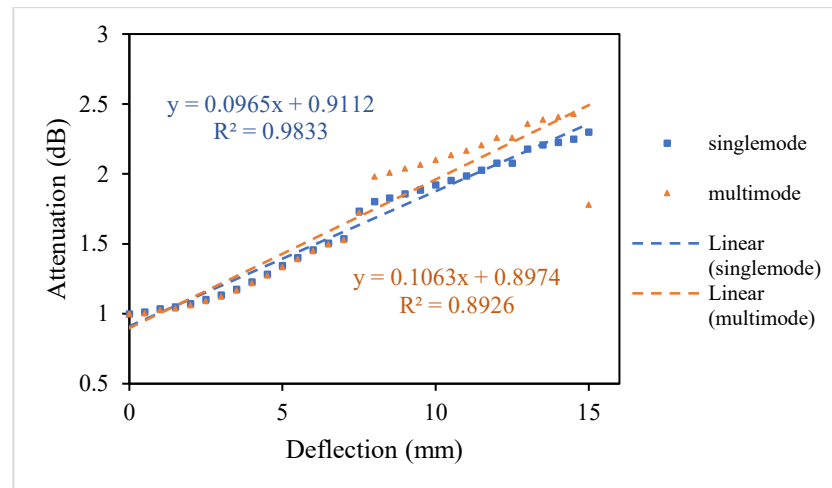
Figure 2. (a) Macrobending system in optical fiber; (b) Macrobending of optical fiber

Bending occurs due to the compressive force that leads to the optical fiber. The location of the optical fiber is in the middle of the bending tool set in a horizontal position. Therefore, the optical fiber will experience interference when the micrometer exerts a compressive force. The disturbance causes the light transmittance in the optical fiber core not to be reflected perfectly. The place where the optical fiber light transmittance is located is in the core. When the middle of the rubber specimen begins to bend, there will be a decrease in the light attenuation value [9].

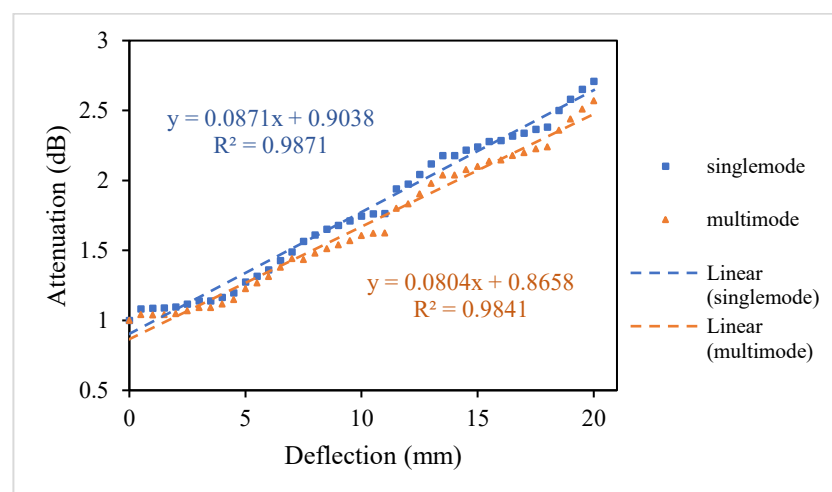
One important consideration when testing macrobending in relation to attenuation is that the voltage values of the two optical fibers must be the same. The same value indicates that the value of light divided by the fiber coupler and received by the photodiode is the same. This principle also applies when calibrating the research system. Calibration is done just before taking each data point. Suppose the voltage values of the reference and modulation optical fibers are the same. In that case, it can be ascertained that the light from both optical fibers is perfectly reflected before the core is damaged. Damaged fiber optic cores result in a decrease in light intensity [10]. If the voltage value between the two optical fibers is the same, there is no attenuation/weakening of light intensity.

The results showed a difference in the voltage value of the optical fiber before and after macrobending. The voltage value is influenced by the number of photons received by the photodiode. When the number of photons is small, the voltage value decreases [11]. The light output intensity on the optical fiber influences the number of photons. The physical parameters of the concrete specimen determine the light intensity of the optical fiber core. Before the core is given macrobending, it has a perfect reflection.

Meanwhile, when the core is given macrobending, the transmittance of optical fiber light will be disturbed [12]. The disturbance results in the fiber optic core being unable to reflect light perfectly. If the light reflection in the optical fiber is not perfect, there is a decrease in light intensity. A photodiode contained in the ADC can detect a decrease in light intensity. When there is a decrease in light intensity, the attenuation of the optical fiber increases [13], as shown in Figure 3.



(a)



(b)

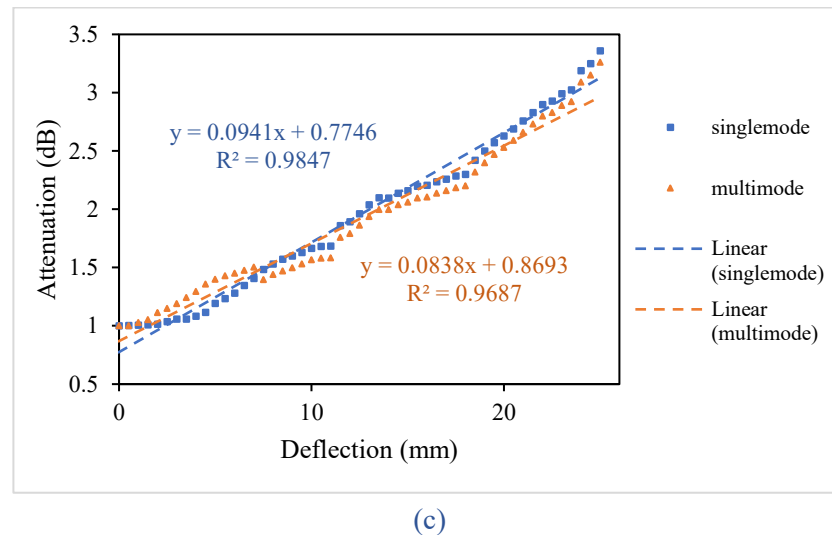


Figure 3. Graph of the effect of deflection on attenuation (a) 0 - 15 mm, (b) 0 - 20 mm, and (c) 0 - 25 mm

The data that meets the specifications to be used as a fiber optic sensor design is the data's most significant gradient and linearity. The sensitivity of the fiber optic sensor is based on the value of the most significant gradient. The linearity of the data is obtained from the increasing attenuation of the optical fiber at each application of compressive force in macrobending treatment [14]. The deflection data given to each single mode and multimode variation is 0-15 mm, 0-20 mm, and 0-25 mm. The data shows that the largest linearity value is at 0-20 mm deflection on single-mode optical fiber. The linearity value is 0.9871.

The macrobending treatment on the optical fiber causes the diffraction angle of the optical fiber to be less than 90°. If the refractive angle is less than 90°, perfect reflection will not occur [15]. This means light is lost from the optical fiber core, decreasing light intensity. The decrease in the modulation voltage value of the optical fiber indicates this. When the modulation voltage gets smaller, the losses get bigger. The increasing gradient value of the research data indicates the amount of optical fiber loss. The gradient value of the data shows the level of sensitivity of the optical fiber that has been reflected. The greater the gradient value, the better the sensitivity. This is because the sensor can detect the small intensity of light transmitted by the optical fiber. In its application, the data can be used for early landslide detection.

In addition, the optical fiber's sensitivity level is based on the linearity of the data. The linearity of the data shows that a slight shift in the X-axis (shift) results in a significant change in the Y-axis (optical fiber attenuation). The linearity of the data is closer to the value of one, the better the sensitivity of the optical fiber [16], [17]. In its application, the data with the largest linearity can

be used for distance sensors, such as landslide sensors. This is because any distance can be detected due to the large linearity of the data.

CONCLUSION

The sensitivity of single-mode optical fiber sensors is higher than that of multimode optical fiber sensors, as indicated by the greater linearity values observed in each deflection treatment. The linearity data for single-mode optical fiber at deflection variations of 0–15 mm, 0–20 mm, and 0–25 mm are 0.9833, 0.9871, and 0.9847, respectively. In contrast, the linearity data for multimode optical fibers are 0.8926, 0.9841, and 0.9687. The characteristic of optical fibers subjected to macrobending in the form of deflection is that as the deflection value increases, the attenuation value also increases. This is due to the decrease in light transmittance through the optical fiber as a result of macrobending.

This study highlights the potential of fiber optic sensors in landslide early warning systems, emphasizing the importance of field testing under diverse environmental conditions. While laboratory experiments provide valuable insights into sensor performance, real-world applications require thorough testing in various soil types, weather conditions, and geographical terrains to ensure reliability. Conducting extensive field trials will help identify potential challenges, such as signal interference, durability issues, and variations in sensor accuracy due to different soil compositions. By validating the effectiveness of fiber optic sensors in landslide-prone areas, future research can refine sensor deployment strategies and enhance the precision of early warning systems. This approach will ultimately contribute to developing a more robust and practical solution for landslide disaster mitigation.

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