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Simulation of Land Movement Detection System Using Accelerometer Sensors and Fiber Optic

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Abstract

Indonesia's geographical conditions are one of the causes of land movement. This land movement can occur due to the movement of rock masses, soil, or debris material making up the slopes. The stability of a slope is influenced by several parameters such as material, soil strength, slope angle, climate, vegetation, and time. In Indonesia, land movement disasters are placed the third rank of natural disasters that occurred throughout 2021. Thus, the development of a land movement detection system is very important for monitoring land movement disasters. In this research, a land movement detection device was developed using the ADXL 335 accelerometer sensor and fiber optic. For data acquisition, Arduino Uno, LEDs, and photodetectors were used. Arduino Uno was used to convert analog signals to digital. In addition, LEDs were used as light sources, and photodetectors were used as a receiver. Changes in the output voltage due to macrobending loss are obtained when the curvature changes due to the pendulum system. The results of the study show that the average acceleration values on the x, y, and z axes of the accelerometer sensor are 0.118 g, 0.925 g, and -2.494 g. The maximum land displacement movement that can be represented by fiber optic is 4 cm. Further, the combination use of accelerometer sensors and fiber optic can show the magnitude of the force that causes displacement, the direction of land displacement, and the magnitude of the land displacement that occurs.

Keywords: *land movement; accelerometer; fiber optic; acceleration*

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INTRODUCTION

Land movement is one of the highest and most frequent disasters in Indonesia. Indonesia's geographical conditions are one of the causes of the land movement. Land movement is a natural phenomenon that occurs due to the movement of rock mass, soil, or debris making up the slope material that moves down or out of the slope due to

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the influence of gravity. Several parameters such as material, soil strength, slope angle, climate, vegetation, and time can affect the stability of a slope. The increase in housing and settlements every year causes several trees that function to withstand landslides to be cut down causing on many landslide points [1]. Based on data from the National Disaster Management Agency [2], cases of land movement are in the third highest rank of natural disasters that occurred throughout 2021. Losses due to land movement disasters not only cause casualties, but damage public and private facilities, and paralyze economic activities. Disaster-affected areas due to transportation routes being cut off. Prevention of landslides can be minimized by using a land movement detection system.

Many land movement monitoring systems have been developed, including the use of Linear Variable Differential Transformer (LVDT) sensors [3,4], accelerometer sensors [5–9], fiber optic [10–13], extensometer [14,15], and inclinometer [16–21]. However, some of these studies, such as [6] dan [9] were more focused on reviewing the angular slope of each axis due to the land movement and testing systems. The study did not provide an analysis of the magnitude of the effect of vibrations that causes land movement. This land movement is very complex because the influence of the magnitude of the vibration can determine the type of movement that occurs apart from the soil structure on the slope. Many parameters can affect the stability of the slope, so it is necessary to combine several sensors to detect land movement. The incorporation of several sensors into the land motion detector aims to increase the accuracy of the tool's performance in the event of a disaster. The combination of several accelerometer sensors with other sensors has been developed. However, some sensor combinations in the study [9,22–24] are still limited to monitoring sensors at ground level. In this research, monitoring of land movement above and below the ground surface will be carried out to detect periodic land movement activity. One of the causes of land movement is vibration, where the center of vibration does not only come from the ground surface. Monitoring of land movement below the ground surface is needed because it can see the movement of the ground due to the movement of the mass of soil below the surface. In addition, measuring land movement above the surface and calculating land movement will influence the results of observations. Yet, installing multiple sensors in one place also becomes less effective because the sensor installation location requires a larger area and costs more.

This research implements the ADXL 335 accelerometer sensor and single-mode fiber optic. Fiber optic was used as a sensor for monitoring land movement because it has several advantages, namely being able to transmit high light, being resistant to corrosion and electromagnetic interference, and having a high accuracy [12,19]. The ADXL 335 accelerometer sensor will represent the magnitude and direction of the land motion, while the fiber optic will represent the magnitude of the land displacement by utilizing macrobending loss. Utilization of the accelerometer sensor is expected to detect early symptoms of land movement by measuring the acceleration of the tool against the earth's gravity. The installation of the ADXL 335 accelerometer sensor above the land surface and fiber optic incorporating a pendulum system is expected to provide good performance in reading the direction of land movement and land displacement.

METHOD

The combination of an accelerometer-based monitoring system and single-mode fiber optic is intended to provide better performance in detecting land movement disasters. The accelerometer sensor functions to measure the acceleration due to Earth's gravity and detects the direction of movement due to the treatment. The main components of the accelerometer sensor are electronic parts in the form of signal processing and mechanical parts. The mechanical part consists of a movable plate and a static plate. When the accelerometer experienced a change in the gravitational force, the capacitance between two plates changes and will affect the output voltage of the accelerometer [7]. The use of macrobending loss in fiber optic is intended to represent the magnitude of the land displacement. Macrobending loss is the loss of fiber optic in which the radius of the bending is greater than the diameter of the fiber optic. The curvature of the fiber optic will create a sharp angle so that light will be reflected back to the core and some of the light will escape through the cladding [25].

The design of the land displacement system based on the accelerometer sensor and fiber optic includes hardware and software design. The hardware design includes electronic modules and interfaces which include the ADXL 335 accelerometer sensor, fiber optic, Arduino Uno, and a computer. The design software includes a data acquisition program using the Arduino Uno IDE software. The block diagram of the land displacement monitoring system can be seen in Figure 1.

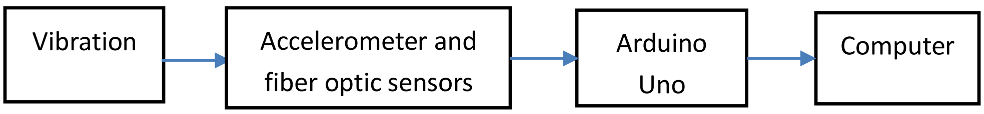

Figure 1. Block diagram of land movement system

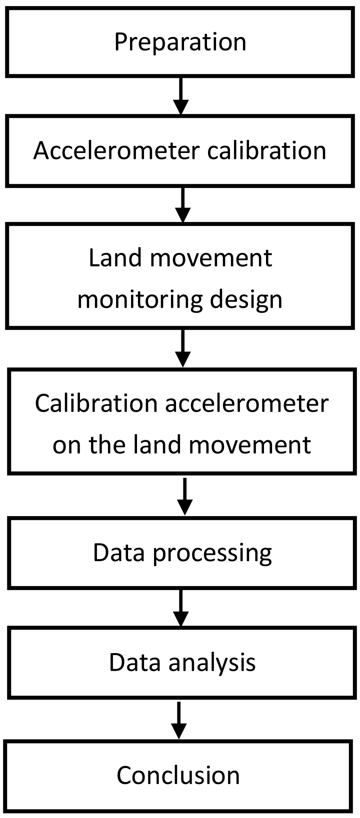

Figure 2. Research flow diagram

The accelerometer and fiber optic sensors will detect land movement. The output data of the accelerometer and fiber optic will be entered into the ADC (Analog to Digital Converter) on the Arduino so that it can assist microcontroller programming. The results of data processing will then be displayed on the computer in the form of voltage and will be processed. The diagram chart of this research can be seen in Figure 2.

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Sec Simulation of Land Movement

The land displacement monitoring simulation is intended to test the performance of the ADXL 335 accelerometer sensor and fiber optic. This simulation is still on a laboratory scale as shown in Figure 3. The vibration simulation is given to a container with dimensions of 41.5 x 29 x 30 cm with a constant in one direction and a slope of 30^{o}. The longer the duration of the vibration, the more soil material will experience displacement. Vibration treatment in the land displacement monitoring system will cause the pendulum to press on the fiber optic. When the pendulum presses on the fiber optic, it will form an angle. The pendulum swing angle can be calculated using Equation (1),

$$\tan \propto = \frac{d}{l} \tag{1}$$

where α is the angle of inclination, l is the length of the pendulum and d is the displacement [26]. The soil used for the simulation is a type of beach sand soil.

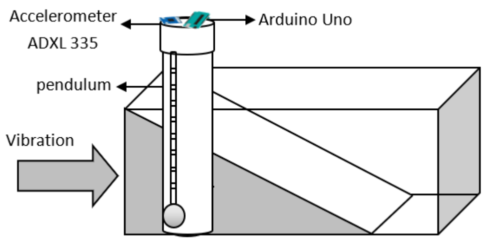

Figure 3. Simulation of land movement sensor using accelerometer sensor and fiber optic

RESULTS AND DISCUSSION

Before testing the land movement system, the accelerometer sensor is calibrated first. The ADXL 335 accelerometer sensor calibration is intended to determine the zero point of the sensor accurately, because the moving elements of the accelerometer sensor are much more sensitive to mechanical stress (shock, shaking) than their electronic parts. To minimize measurement errors when installing the accelerometer system, the accelerometer must be calibrated after the system is installed [27]. The results of the offset voltage and accelerometer sensor sensitivity using calculations [28] are shown in Table 1. The test results show the sensor sensitivity on the x-axis is 0.332 V/g, the y-axis is 0.359 V/g, and the z-axis is 0.355 V/g. The results of the research on the sensitivity value of the accelerometer sensor on each axis are still within the sensitivity range of the datasheet [5]. Therefore, the accelerometer sensor has a good sensitivity value according to the standards from the datasheet and is suitable to be used in the land movement system.

Table 1. Offset voltage and sensitivity of ADXL 335 accelerometer sensor

Axis	V_{offset} (V)	Sensitivity (V/g)
x-axis	1.68	0.332
y-axis	1.75	0.359
z-axis	1.72	0.355

The results of testing the land motion detection system using the accelerometer sensor can be seen in Figure 4. Figure 4 shows that the output voltage on the x-axis at the beginning of the vibration until the vibration ends is at the output of 0 V. The output voltage value on the x-axis is not always constant, due to the sensing axis which causes the value of the output voltage to be affected. When the sensing axis being referenced changes, the other two axes will be affected. This can be seen in the value of the output voltage generated by the accelerometer sensor for each axis when given the influence of vibration. The influence of the accelerometer sensor calibration is what plays an important role in determining the direction of the axis orientation to the earth's gravity. In the test device simulation, the vibration given is not constant and the direction of the vibration is parallel to the y-axis.

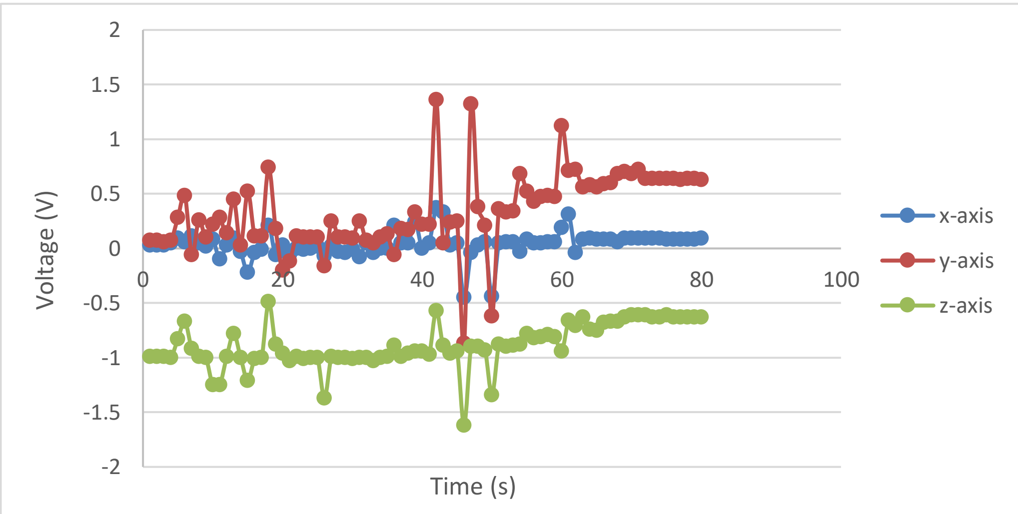

Figure 4. The results of the accelerometer sensor readings after being treated with vibration

Figure 4 also shows that from the first to the fourth second there is no change in the output voltage of the accelerometer sensor. This shows that there is no vibration effect. When the fifth-second accelerometer sensor changes, it shows the effect of the first vibration experienced by the ground movement tool. From the fifth second until the 62nd second, the y-axis and the z-axis experience a change in the output voltage in the form of a sinusoidal function. It is connected to the x-axis when first given a constant value vibration treatment. This is because the x-axis is the axis of rotation so only the y- and z-axes change. The placement of the accelerometer sensor in a plane will affect the direction of the sensing axis. When the accelerometer sensor reads vibrations, the sensor will follow changes that change its orientation to the gravity [29].

Figure 5 shows the calculation results of the accelerometer sensor's gravitational acceleration. The average acceleration of the accelerometer sensor on each axis when given a non-constant vibration is 0.118 g on the x-axis, 0.925 g on the y-axis, and -2.494 g on the z-axis.

A large accelerometer sensor acceleration value indicates a large vibration treatment as well [28]. This causes more soil to hit the detection device and make the fast device experience a drastic slope. The acceleration value on each axis shows the magnitude and direction of the vibration received by the accelerometer sensor. Figure 5 also shows the magnitude of the vibration acceleration which can be read by the accelerometer sensor. When the system detects a movement and a vibration, a landslide is likely to occur. This way, the magnitude of the detected acceleration can detect the level of risk caused by the vibration [28,30].

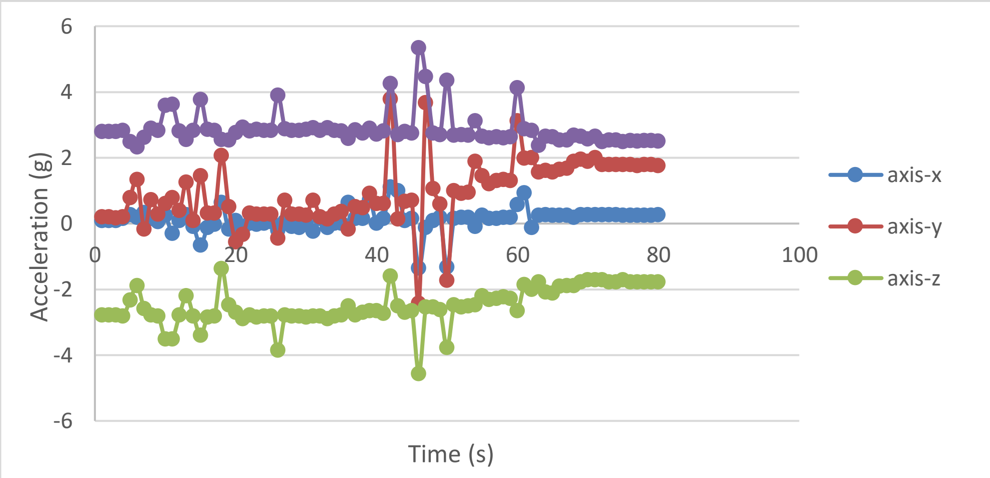

Figure 5. Acceleration of each axis on the accelerometer sensor

Figure 6 demonstrates the result of the fiber optic output voltage reading when given vibration treatment. The output voltage reading is obtained from the motion of the pendulum against the fiber optic. When the pendulum presses against the fiber optic, the light will escape from the cladding and the photodetector will detect less light. From the tenth second to the 57th second, the fiber optic output voltage reading fluctuates which can be seen in the red circle in Figure 6. Then, the fiber optic swings or bounces back which causes the fiber optic to stretch again. The fiber optic that is stretched again makes less light come out of the fiber optic and more light received by the photodetector. The 63rd second to 80th second produces a decreasing voltage change which indicates that the pendulum has compressed the fiber optic to the maximum and the land movement detection device has reached its maximum slope. The maximum displacement that can be estimated is 4 cm.

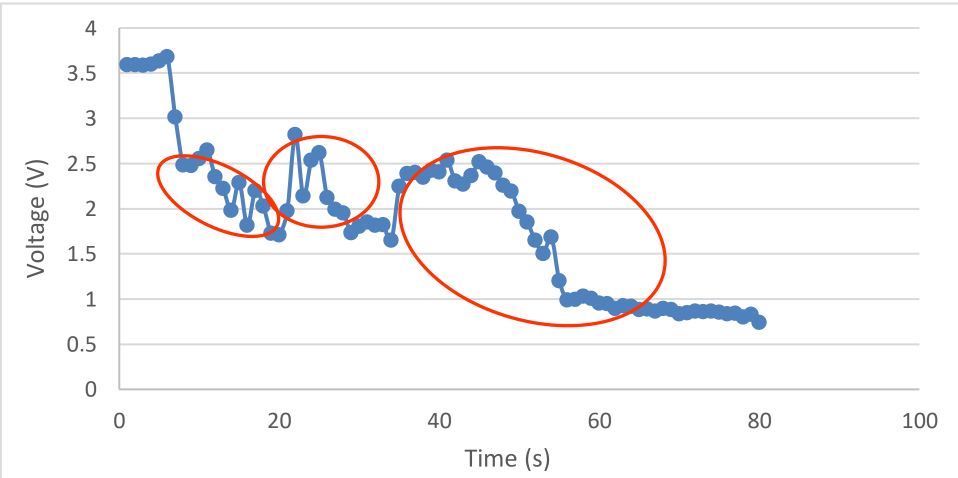

Figure 6. The result of output voltage fiber optic

In addition, Figure 6 shows the duration of sensor displacement to the output voltage due to vibration by utilizing the macrobending loss of single-mode fiber optic. This displacement starts from the utilization of the indentation of the fiber optic which has not been subjected to vibration treatment until the maximum sensor displacement. When this curvature becomes smaller, as a result, the intensity of the light emitted will experience a change in the output voltage read [12]. It is worth noting that this study uses the structure of soil materials of sand. The difference in the material used in the test will affect the difference in the output voltage on the fiber optic [31].

Based on the test results of the accelerometer sensor and fiber optic, it can be concluded that the system can respond to land movement due to vibration. The simulation of this laboratory-scale land movement tool is still limited to measuring land movement with small-scale test materials. Tests using several soil material structures can be carried out to be able to categorize the types of soil movements that can be detected by the soil movement tools. When the tool is to be implemented in real conditions in the field, more sensors are needed. The tool can be installed at several high-altitude points. However, the mechanical system of the sensor body housing needs to be fixed. This is to minimize fluctuating output. Further research can unfold to improve the mechanical system of the body sensor housing and the application of the internet of things in the appearance of reading sensors.

CONCLUSION

This study designed a land movement device based on accelerometer sensors and fiber optic. The results showed that the accelerometer sensor can represent the magnitude and direction of land movement, while fiber optic can represent land displacement. When the vibration is given to the soil continuously where the magnitude of the vibration is not constant, it will trigger the occurrence of land movement and soil mass transfer. This accelerometer sensor can be used to detect above-ground level movement, while fiber optic can be used to detect below-ground level movement. The results of accelerometer and fiber optic sensor measurements have the potential to be monitored in real-time using internet of things technology.

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AUTHOR CONTRIBUTIONS

Qonitatul Hidayah: Conceptualization, Methodology, Validation, and Writing-Original Draft; Umi Salamah: Software, Formal Analysis, and Validation; and Yuda Wiges Pratama: Data Curation, Project Administration, and Writing-Original Draft.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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