Landslide monitoring system based on fiber optic sensor and CCD TSL1401CL linear sensor array

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Abstract. A landslide monitoring system using fiber optic sensor and CCD TSL140CL linear sensor array has been designed. Fiber optic sensor was designed to sense the displacement of landslide and CCD TSL1401CL linear sensor array was used to measure the rain intensity. The data of landslide and rain intensity send using GSM SIM 900A module to personal computer which paired with GSM Wavecom modem as a receiver. The result of the testing derived that fiber optic sensor which has been designed can monitor the displacement with 0.59 % of error percentage. Monitoring system of landslide can display rain intensity, displacement of landslide, and condition of landslide in real time to PC as early warning.

1. Introduction
Landslide is a material displacement of slope former phenomenon such as rocks, soil, or compound material that move to the downward of slope by spontaneously or slowly. The landslide phenomenon often occurs in the slope of hills area. One of the cause of landslide is rain that disrupt the stability of slope materials. The high of rain intensity and in a long duration caused the landslide. Water from rain intensity induce the cohesion between the soil particle and move independently. The addition of water increase the pore pressure and decrease the normal pressure in the slope. This caused the slope failure and landslide because the water of high rain intensity.

The previous research has been done to monitor landslide using extensometer as displacement sensor. There are two types of extensometer such as wireline extensometer and optical extensometer. Wireline extensometer is one of electrical extensometer which be able to monitor the landslide with utilizing the vibrated frequency of wire. The example of wireline extensometer is LVDT sensor. LVDT sensor utilizes the electromagnetic transducer by converting the object motion and combined mechanically into suitable electric signal[1]. The utilization of wireline extensometer has the weakness of being able to transpire the noise due to electrical interference which could induce damage to the extensometer.

Optical extensometer is a device that functions to measure the displacement of object an object in horizontal axis based on light[2]. Optical extensometer use optical fiber as landslide detector. In the application, most of optical fiber used in any filed such as industrial manufacturing, geophysics survey, and in mitigation disaster[3]. Optical fiber is made from insulator material which could be
able to guide the light to minimalize the noise and the effect of electromagnetic wave in aftermath, resulting the interference of instruments. The principle of the sensor is measuring the alteration of light intensity which propagate in the optical fiber. Optical fiber will have the alteration of bending loss caused by the landslide[4].

Herlin[5] made the landslide displacement sensor using optical fiber based on Internet of Things (IoT). This optical fiber sensor using single winding with diameter alteration variance of number of optical fiber. Till the output voltage and bending loss reach the maximum value, than required the addition number of optical fiber winding. Based on previous research required the instrument that be able to measure a parameter that cause landslide, one of the is the intensity of rain.

Based on the previous research and the problems, landslide monitoring system based on optical fiber sensor and CCD TSL1401CL linear sensor array has been designed. This designed system consist of rain intensity sensor block, optical fiber sensor block, telemetry system, and display. Measuring system of rain intensity consist of components such as He-Ne laser, lens, and CCD TSL1401CL linear sensor array. The utilization of CCD TSL1401CL has the advantage in raindrop detection. The raindrop that detected on CCD TSL1401CL derived the analog and digital signal. The analog signal processed to produce the imaging of raindrop. The landslide displacement will detected using optical fiber optic consist of optical fiber FD 620-10, photodiode, and laser diode. The telemetry system using module GSM SIM900A as transmitter and modem GSM wavecom as receiver.

2. Method

2.1. Design of Overall Experiment of Landslide Monitoring System

Design of landslide displacement monitoring system hardware showed in Figure 1. There are two main blocks of hardware system such as data transmitter block and data receiver block. The data transmitter block consist such as He-Ne laser, CCD TSL1401CL linear sensor array, laser diode, optical fiber, photodiode, arduino uno and GSM SIM900A module. The data of rain intensity and landslide displacement will be processed in arduino uno and sent into GSM SIM900A module and received by GSM Wavecom module.

![Figure 1. Block diagram of landslide monitoring system](image-url)

Receiver data block consist such as GSM Wavecom modem, arduino uno, and Personal Computer (PC). The received information by GSM Wavecom modem such as rain intensity, landslide displacement, and warning condition will be saved in PC. Design system of software aims to process the input signal from CCD TSL1401CL and photodiode until the data will be sent by GSM SIM900A module. There is source code that implanted into microcontroller of arduino uno using C language.
The program that has been implanted will determine the work sequence of microcontroller. In general, the program flowchart of landslide displacement and rain intensity showed in Figure 2.

**Figure 2.** Software flowchart of (a) transmitter unit (b) receiver unit

2.2. *Design and Experiment of GSM SIM 900A Module and GSM Wavecom Modem*
Series of GSM SIM 900A module and GSM Wavecom modem experiment has been done with sending a message by counting the sent time with variation of transmission distance. GSM SIM 900A module as data transmitter will send a message to GSM Wavecom modem as data receiver. Series of GSM SIM 900A module showed in Figure 3.

![Experiment scheme](image)

**Figure 3.** Experiment scheme of (a) GSM SIM 900A module (b) GSM Wavecom modem

The experiment of data receiver part requires Personal Computer (PC) and GSM Wavecom modem. GSM Wavecom modem experiment has been done to find out how long the received time of message with variation of transmission data distance. The sketch of GSM Wavecom modem showed in Figure 3.

2.3. Data Analysis

Data analysis is a process to find out the accuracy of measurement system. Data analyze performed to get the conclusion of measurement. The accuracy is suitability level of measurement result toward the true value. The accuracy of system determined from the error percentation between the true value with the measurement value. The error percentation of measuring instrument determined with Equation 1.

\[
e_{n} = \left| \frac{Y_{n} - X_{n}}{Y_{n}} \right| \times 100\%
\]  

(1)

\(Y_{n}\) is the true value of comparison instrument and \(X_{n}\) is the measure value of measuring instrument. The comparison instrument that used was a crossbar.
3. Summary and Result

3.1. The Calibration of Optical fiber Sensor as The Landslide Displacement Sensor

The optical fiber sensor experiment has been done to observe the accuracy of system which has been designed with measuring instrument comparison. Based on the previous experiment laser diode with 150 Ω of resistance and triple windings used for making the optical fiber sensor as a displacement sensor. Length of displacement which can measured by optical fiber suitable with the radius of optical fiber bending was 10 cm with 1 cm interval each displacement.

![Graph of displacement value comparison between crossbar and optical fiber sensor](image)

**Figure 4.** The graph of displacement value comparison between crossbar and optical fiber sensor

Figure 4 showed the orange curve was the comparison instrument value and the blue curve was the optical fiber sensor value. Trend between of two curve have the same linear slopes. The experiment result showed that the average error was 0.59%. Based on the data from Figure 4 can be concluded that optical fiber sensor can operate properly.

3.2. Experiment of GSM SIM 900A Module and GSM Wavecom Modem

The testing of telemetry data system consist of two units such as GSM SIM 900A Module as transmitter unit and GSM Wavecom modem as receiver unit. The experiment has been done with counting the time when SMS has been sent to GSM SIM 900A module until received by GSM Wavecom modem and variation of distance between transmitter and receiver. Variation of distance between transmitter and receiver has been done to find out if GSM SIM 900A module and GSM Wavecom modem works fine if the distance getting far. Data variation that used was 1 m, 10 m, 100 m, 1 km, and 10 km. The data result showed in Table 1.

| Table 1. Testing result of sending data to GSM Wavecom modem |
|---------------|--------------|--------------|
| Distance (m) | Sending Time (s) | Information |
| 1             | 1             | Sent         |
| 10            | 1             | Sent         |
| 100           | 1             | Sent         |
| 1,000         | 1             | Sent         |
| 10,000        | 1             | Sent         |

Table 1 shows the data result transmitter of GSM SIM 900A module to GSM Wavecom modem. The experiment has been done with GSM SIM 900A position at Lubuk Lintah, Padang. The result testing prove that distance variation was not affect the data transmission time. It is because GSM SIM
900A module as transmitter and GSM Wavecom modem as receiver using electromagnetic wave which has a same speed with the speed of light so that the data transmission from GSM SIM 900A module success to send to GSM Wavecom modem.

3.3. Overall Experiment of Landslide Monitoring System

The experiment of monitoring system involve unification between hardware and software. The experiment of landslide monitoring system has been done to find out system ability of each block. Landslide monitoring system operate by using 12 V of solar cell as voltage source where the input voltage of each sensor was 5V. The physical design of landslide monitoring system showed in Figure 5.

![Figure 5. Physical design of landslide monitoring system](image)

Transmitter unit consists of rain intensity sensor and displacement sensor. The data retrieval area made with model of artificial rain and slopes. Rain intensity sensor block obtain the data from artificial rain modeling which is made using PVC as waterways with holes on it top that becomes the rainfall. Landslide sensor block obtain the data from the artificial slopes modeling. The top of artificial slopes intalled the PVC with holes as artificial rain. The artificial slopes consists of two different layers of soil such as clay mixed with rocks at bottom layer and crumbly soil at top layer. The difference type of soil forms into discontinuity area so that landslide can occur.

The water flow through PVC with water pump support in order to go up as artificial rain and fall to the rain intensity sensor area and artificial slopes. When the rain fall, the rain intensity sensor will detect the raindrop with number of ADC output and raindrop diameter and wet the surface of artificial slopes. The artificial slopes area that scrapes by raindrop caused the second post that connected with landslide displacement sensor slip downward. When the second post was slipped, optical fiber that connected with the chain to second post will pulled. The pulled optical fiber forms vertical multiple bending. Multiple bending induce bending loss of optical fiber with the decrease of light intensity and detected by photodiode with output voltage. The output voltage transformed to the length unit with getting transfer function from characterization. The displacement data, landslide condition, and rain intensity will be saved in arduino uno and sent to SIM 900A module as receiver unit.
Receiver unit consist of personal computer as data display and GSM Wavecom modem as receiver unit instrument. The received data from GSM Wavecom modem will be displayed into Microsoft Excel. Table 2 showed the received data and displayed into Microsoft excel.

Table 2. Testing result of landslide monitoring system

| Time            | Rain Intensity (mm/minute) | Displacement (cm) | Condition       |
|-----------------|----------------------------|-------------------|-----------------|
| 1:34:17 PM      | 1.31714                    | 1.02              | SAFE            |
| 1:36:17 PM      | 43.06394                   | 4.02              | STAND BY        |
| 1:37:19 PM      | 107.03690                  | 5.02              | DANGER          |

Table 2 showed landslide condition when rainfall damp the surface of artificial slopes. The artificial rain occur until the displacement sensor indicate that displacement at slopes ≥ 5 cm. The “Safe” condition derived rain intensity with 1 minute of duration and 1.31714 mm/minute of rainfall intensity and 1.02 cm of displacement. The magnitude of rain intensity affected by duration of rain so that based on Table, the more duration of rain, the more of rain intensity. When the landslide displacement ≥ 5 cm with “Danger” condition, the rain intensity was 107.03690 mm/minute with 5.02 cm of displacement. The high rain intensity cause the decrease of soil cohesion and possible the soil move like a liquid [6]. The excess of water caused by high rain intensity will decrease the friction and causing landslide.

4. Conclusion

Based on experiment and analysis of landslide monitoring system with affect of rain intensity can be concluded that the experiment result of landslide monitoring system using optical fiber sensor and CCD TSL1401CL linear sensor array can detect the landslide displacement that affected by rain intensity so that the data sent to the receiver for landslide disaster mitigation. GSM SIM 900A module can send the data to GSM Wavecom modem that used as telemetry system of landslide monitoring system with display on PC. The result of optical fiber sensor with comparison instrument has 0.59 % of error percntation.

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