High resolution extensometer based on optical encoder for measurement of small landslide displacements

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Abstract. There are many ways to measure landslide displacement using sensors such as multi-turn potentiometer, fiber optic strain sensor, GPS, geodetic measurement, ground penetrating radar, etc. The proposed way is to use an optical encoder that produces pulse signal with high stability of measurement resolution despite voltage source instability. The landslide measurement using extensometer based on optical encoder has the ability of high resolution for wide range measurement and for a long period of time. The type of incremental optical encoder provides information about the pulse and direction of a rotating shaft by producing quadrature square wave cycle per increment of shaft movement. The result of measurement using 2,000 pulses per resolution of optical encoder has been obtained. Resolution of extensometer is 36 µm with speed limit of about 3.6 cm/s. System test in hazard landslide area has been carried out with good reliability for small landslide displacement monitoring.

1. Introduction
Landslides are among the most common and damaging natural hazards in terms of human lives and infrastructure damage. A landslide is a phenomenon of mass movement, which moves small displacement per day in wide area. The observation of landslide together with geophysical, hydrological, and environmental parameters helps to reveal the relationships between movements and different parameters, which is necessary to develop sensors used in landslide detection.

An extensometer is a sensor for landslide detection that measures extended or contracted distance of interest in a material when it is elongated and compressed such as in a tension test. A contact type of the extensometer measures the strain of material by directly attaching a sensor to the specimen of a material [1]. It is easy to measure the overall elongation or compression. However, when the material to be measured is small and not enough to fit to the clamp of a loading device, or the deformed rate is not uniform along the elongated (or compressed) direction, it is hard and even impossible to find out the strain using contact type extensometer [2].

The other monitoring techniques for landslide displacement detection, such as using multi turn potentiometer [1 – 3], space-borne or ground-based synthetic aperture radar (SAR) interferometry [4 – 6], fiber optic strain sensors [7, 8], and geodetic measurements (GPS, EDM, etc.) [9, 10] have been shown to be an effective complementary tool for landslide monitoring. However, highly sensitive extensometer is essential to measure small landslide displacement for a long period observation.

In this work, an optical encoder has been used to produces pulse signal with high stability of measurement resolution despite voltage source instability. It also has the ability of high resolution for
wide range measurement. Developed extensometer using optical encoder has been tested and evaluated to meet the requirements for measurement of small landslide displacement. The extensometer also utilizes wireless communication, so that it can be used as a landslide early warning system [11].

2. Methodology
An optical rotary encoder uses optical sensing technology that has a rotation code and a pattern on it. The incremental optical encoder is the most widely used of all rotary encoders due to its low cost and ability to provide signals that can be easily interpreted to provide motion related information such as velocity or change in position. Figure 1a shows how incremental optical encoder provides information on instantaneous position of a rotating shaft by producing two output square wave cycles per increment of shaft movement. The two output wave forms are 90 degrees out of phase that usually called quadrature signals.

![Figure 1. Working principle of incremental optical encoder.](image)

In figure 1b, the quadrature signals are digital signals that produce two channels, channel A and channel B. When optical encoder rotates in a clockwise direction, channel A leads channel B. If optical encoder rotates in counterclockwise direction, channel B leads channel A. When more resolution is needed, it is possible for the counter to count the leading and trailing edges of the quadrature encoder’s pulse train from one channel, which doubles (x2) the number of pulses per revolution. Counting both leading and trailing edges of both channels, a quadrature encoder will quadruple (x4) the number of pulses per revolution. For example, if we have 2,000 pulses per revolution (ppr) quadrature encoder, it can be increased to a maximum of 8,000 pulses per revolution (ppr) counter data.

3. Results and discussion

3.1. Design of extensometer system
In order to make optical encoder as extensometer, we used optical encoder with 2,000 pulses per revolution (ppr) and the microcontroller circuit that contains an 8-bit ATMega8A microcontroller to detect quadrature signal. It is then calculated as counter/position measurement. For monitoring purposes, wireless communication using WI-FI module was integrated to a 3G/GPRS gateway system and connected to a cloud system. We also used dual voltage regulators to supply the component system from variable range voltage of external power sources. The block diagram of the system is shown in figure 2a.
Figure 2. (a) Block diagram and (b) hardware realization of extensometer system.

A system is placed inside a weatherproof box as shown in figure 2b. A spring disc merges to wire drum, and it is also attached to optical encoder. In case of displacement, a still wire will roll up the drum and rotate the spring disc. An optical encoder measures the rotation of spring disc (in degree), where it can be converted to the actual displacement (in cm). The steel wire from extensometer can be pulled up to reach a length of 1.5 meters. Figure 3 shows the works flow of developed extensometer system. The system starts by initializing an interrupt. Microcontroller reads every change from the optical encoder and calculates the displacement from the pulse signal. Microcontroller updates the system data, and sends the data to the gateway system. If there is no power loss, the system will repeat the reading for every minute.

Figure 3. Flowchart of extensometer system.
3.2. System characterization

To obtain relationship between optical pulse counter signals with the actual position, we have to characterize the system by comparing the measurement distance to a standard length. By doing a comparison measurement every distance from 0.5 cm to 20 cm, we get the measurement result of optical encoder as linear equation as shown in figure 4. The linear regression results is \( y = 0.0036x + 0.11354 \), in which \( y \) is length in cm and \( x \) is pulse counter. The equation is used for microcontroller system to calculate the distance of each change of pulse counter. The resolution of equation is 0.0036 cm.

![Figure 4.](image)

**Figure 4.** The system characterization of extensometer.

Figure 5 shows errors as the difference between the values obtained from the regression calculations and the actual measurements. Errors from the calculation tend to increase in proportion to its pulse counter value. In the measurement range of 20 cm, the largest absolute measurement error is 0.36 cm. Another factor that should be concerned is the speed of pulse counter from the optical encoder. If the speed counter of 1 kHz is used in the microcontroller system, the speed limit of displacement should not exceed 3.6 cm/s.

![Figure 5.](image)

**Figure 5.** Absolute error of regression calculation.

3.3. Testing system in real condition

The extensometer system based on optical encoder was tested and evaluated in hazard landslide area starting from November 10, 2016 to January 25, 2017. Location with high risk of landslide
occurrence, which is km. 107 of railway track in Purwakarta, West Java, was selected as the evaluation site. Figure 6 shows the evaluation site with extensometer is placed on high stand rather than on the ground.

![Figure 6. Testing site for extensometer in a hazard landslide condition.](image)

The extensometer system measured and recorded activities not only from landslide movement but also surrounding conditions. For examples, wind and vegetation around the extensometer system will cause changes in the system, e.g. steel wire being pulled from the extensometer due to vegetation growth. These changes may cause incorrect recorded data in the system. By providing a sheath in the surrounding system will reduce some disturbances to the system and correct the recording data (figure 7).

![Figure 7. Monitoring landslide displacement using extensometer.](image)

4. Conclusion
The extensometer system has been designed and tested using 2,000 pulses per resolution of optical encoder. The system has measurement resolution until 0.0036 cm with speed limit of displacement not exceeding 3.6 cm/s. In the measurement range of 20 cm, the largest absolute measurement error is 0.36 cm. The testing system in hazard landslide area has been reported in good reliability for monitoring small landslide displacement.
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