Study of soil moisture sensor for landslide early warning system: Experiment in laboratory scale

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Abstract. The high rate of rainfall is the main trigger factor in many cases of landslides. However, each type of soils has unique characteristics and behavior concerning the rainfall infiltration. Therefore, early warning system of landslide will be more accurate by monitoring the changes of ground water condition. In this study, the monitoring of ground water changes was designed by using soil moisture sensor and simple microcontroller for data processing. The performance of soil moisture sensor was calibrated using the gravimetric method. To determine the soil characteristic and behavior with respect to water content that induce landslides, an experiment involving small-scale landslide model was conducted. From these experiments, the electric resistance of the soil increased as soil water content increases. The increase of soil water content led to the rise of the pore pressure and soil weight which could cause soil vulnerability to the movement. In addition, the various soil types were used to determine the responses of soils that induce the slope failure. Experimental results showed that each type of soils has different volumetric water content, soil matrix suction and shear strength of the slope. This condition influenced the slope stability that trigger of landslide.

1. Introduction
Landslide is a disaster with highest prevalence around the world [1-3]. Global climate change, population increase and economy development had led to rising trend of landslide frequency and pose hazard to the population [4-5]. To reduce losses caused by landslides, an early warning system is required. Earthquake, volcano activities, rainfall and human involvement with the nature are triggering factors of landslides [6-10]. According to historical data of landslide, rainfall became the main trigger for many landslides. As the intensity and duration of rainfall increase, infiltration of water into the soil rises. This situation has affected for increasing its weight and pores. When the water steadily enters the impermeable soil which acts as a sliding plane, the ground becomes unstable and the weathering caused ground movement. The change of water content in the soil account for the difference in soil properties, reducing soil strength and matrix suction [4, 9-14]. Usually, rainfall is measured using rain gauge, but it requires the specific rainfall threshold values for either regional or local areas [8]. Moreover, the rate
of water infiltration into the ground is influenced by covering vegetation, topography, water seepage and soil characteristics [8, 9, 11, 15, 16]. The effective method to design an early warning system of landslide is by monitoring groundwater content changes.

Various methods have been developed for measurement of ground water content such as Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), Ground Penetrating Radar (GPR), and neutron scattering. These methods, while possessing high accuracy, however they are expensive, requiring high frequency, and pose hazard to the environment [17]. On the other side, there is a safer and simpler method for groundwater content sensing using a resistive sensor [6, 17, 18]. One of the studies that used the resistive sensor for an early warning system of landslide was conducted by Ref. [6] but the sensor was expensive. Therefore this study used a low cost sensor which can be conveniently used. The system consists of a measuring sensor and processing data using microcontroller. The measurements were done using a laboratory scale landslide model with two types of soil samples. This experiment was conducted to determine the effect of water volume to difference in soil characteristics inducing landslides.

2. Design and Calibration

The study for developing an early warning system for landslide through changes in groundwater content was done in several stages. The first stage was design and characterization of instrumentation system that measures the physical changes. In this experiment, a resistive sensor was used to determine changes in soil water content. The basic principle of this sensor was that the increase of water content will lower the resistance that causes the drop on the measured voltage. This relation is described by Equation. (1).

\[ V = I \cdot R \]  

where \( V \) is the voltage measured, \( R \) is the resistance of the ground that changes according to the variation in the content of groundwater while \( I \) is the electrical current.

The block diagram of the instrumentation system is shown in figure 1(a) that consists of a resistive sensor, signal conditioning circuit, data converter, microcontroller and computer. The signal conditioning circuit shown in figure 1(b). In principle, this circuit is a sample voltage divider circuit and op-amp as an amplifier. The output of this circuit will be processed by the microcontroller to be converted to digital data using its internal 10-bit ADC.

![Figure 1](image)

**Figure 1.** (a) Block diagram of the system in measuring the change in groundwater content. (b) signal conditioning circuit

The sensor calibration was conducted to get an accurate measurement data. Two sample were used for calibration, soil and sand, which have different water contents and structures. This was proven by the measurement of soil moisture using a gravimetric method [17]. Gravimetric method is a commonly used method in determining soil moisture. The tested samples was first weighed, and then dried in the oven at a temperature of 105°C for 24 hours. To determine the moisture content of the sample, Eq. (2) is used.
\[
\%m = \left( \frac{\text{soil mass}_{\text{wet}} - \text{soil mass}_{\text{dry}}}{\text{soil mass}_{\text{wet}}} \right) \%
\]

where the weight of dry soil, wet soil and water are written as \(\text{soil mass}_{\text{dry}}\), \(\text{soil mass}_{\text{wet}}\) and \(m\), respectively. In the measurement stage, a simple and small landslide model was developed to simulate the similar condition in the field. The landslide chamber design can be seen in figure 2. The soil samples were inserted into the chamber with a slope of ±50\(^\circ\) and the sensor was placed in particular depth and then added with water by certain volume within several time.

\[\text{Figure 2. Design of landslide model}\]

3. Result and Discussion

For the calibration and characterization of sensor with respect to the change of water content of soil, a measurement was carried out on the samples prepared for the gravimetric method. A total 25 gram samples was divided and inserted into eleven boxes and then added with various volume of water. The measurement of the sample was conducted 2 days after the addition of water.

\[\text{Figure 3. Design of landslide model}\]

Figure 3 shows the relationship between the sensor response and the change volume of the water content. It is shown that the addition of water reduces the soil resistance exponentially. This result is in accordance with the characteristic of resistive sensor response. However, the addition of water did not reduce the soil resistance when the addition of water was greater than 16 mL, which happens because
the soil reached saturation state. On the other hand, both types of samples have similar tendency response characteristics.

![Figure 4](image1)

**Figure 4.** Landslide simulation (a) before event, (b) after event, (c) sensor response for the soil sample

![Figure 5](image2)

**Figure 5.** Landslide simulation (a) before event, (b) after event, (c) sensor response for the sand sample

In an effort to reduce losses and casualties that may result from landslides, real time monitoring of prone areas to landslide events is required. To determine the response of the soil to the change of water content which can trigger landslides, simulation of landslide in laboratory scale was done using two types of samples as shown in Fig. 4 for the soil sample and Fig. 5 for the sand sample. These figures
showed the condition of the slope before and after the addition of certain volume of water as well as the
sensor response to these changes. In this experiment, different types of soils were used to determine the
effect of soil on landslide. Generally, every type of soils has unique characteristics such as material
composition, porosity and bulk density. These characteristics related to soil strength, pore pressure and
matrix suction of the soil. The higher the organic materials are embedded in soil, the granular structure
and pore of the soil become higher but its bulk density lowers. As the flow of water and air in the soil is
influenced by pore, the bulk density will therefore affect the capability of matter through the soil [20].

The simulation to see the effect of change in groundwater content to the stability of the slope was
performed using soil sample (fig. 4) and sand sample (fig.5). Both samples had different initial water
contents, 25% for the soil and 13% for the sand samples, based on the measurements using the
gravimetric method. These initial conditions indicated that the soil is moisture than the sand. This result
was comparable to the initial response of the sensor where the soil had smaller resistance than the sand
did. Therefore, it can be concluded that the addition of water will lower the resistance of soil.

The simulation results of the two samples show that each type of soils has its own characteristics that
affect the stability of the slope. The soil has strong cohesion between each particle hence any additional
amount of water does not directly lead to landslides, while the sand has smaller attractive force between
its particles thus it is prone to landslides with addition of water. In addition, the sand has small pore and
low organic matters, therefore it has low capability to absorb, hold and transport the water into the deep
layer [20]. Based on these simulations, the soil strength and matrix suction of soil were higher than those
of sand. Therefore, the soil has higher threshold value of water. This was proven from the simulation
where the addition of water of 3600 mL to the soil did not cause landslides, while the addition of water
of 3200 mL to the sand led to the occurrence of landslides. The threshold values of water for each type
of soils are different then the measurement of groundwater content was more accurate than rainfall
intensity.

4. Conclusion
The soil moisture sensor for the landslide early warning system has been studied. The system was
developed by using a signal conditioning circuit and digital converter of the ATMega 328
microcontroller with internal 10-bit ADC. Based on the conducted initial studies, it can be concluded
that pore pressure, soil strength and matrix suction for each type of soils are different. This affected the
determination of the threshold value regarding to the change of groundwater content that causes
landslides. Therefore, the monitoring of water content change is more suitable method to develop the
early warning system than the rainfall measurement.

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