Development of low-cost instrumentation for landslide early detection model

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Abstract. This research is intended to make early detection system. A landslide-prone land contour model has been constructed and equipped with an instrumentation system for early monitoring and mitigation which includes: rainfall monitoring, soil movement, moisture and slope monitoring. The model of landslide developed is a model of landslide triggered by rainfall that moves soil mass, so accurate rainfall measurement is necessary. A portable tipping bucket rain gauge system has been manufactured, tested and compared to BMKG tipping bucket rain gauge for two months with excellent results. Unpredictable ground movements will accurately affect the sensor measurement results. The test results show the response of the ground movement sensor is very important to issue the condition. There are 3 conditions when the system shows the cues, namely: ALERT (movement> 2cm); DANGER (movement> 4cm) with alarm buzzer alarm indicator; IMMEDIATELY EVACUATION that is when the land has hit a hedge fence accompanied by alarm sirens sound indicator.

1. Introduction

Indonesia region is geologically traversed by two paths of the world's young mountains of the Mediterranean Mountains in the west and Pacific Circle Mountains in the east causing Indonesia to have many volcanoes that are active and prone to disaster. The existence of this volcano path causes some areas of Indonesia to form mountains and hills with a slope of a sloping slopes to steep [1]. This condition causes Indonesia to have potential landslide disaster that can cause loss of life, loss of property, and environmental damage.

The landslide disaster is local, but it is spread throughout Indonesia. The number of occurrences of landslides is increasing when entering the rainy season especially in the steep hilly areas [2]. The number of incidents of landslides in Indonesia has not been maximally anticipated, as evidenced by the many incidents that cause many victims. Efforts to mitigate landslide disasters are still focused on retrofitting slope structures and stability while community empowerment approaches and early warning systems are still poorly optimized to reduce greater damage or losses [2]. Therefore, disaster mitigation needs to be done to minimize the impact.

Minimization of the victim can be done if it can predict the natural changes accurately with a continuous monitoring system. The monitoring system can be a data acquisition system that contains data on the causes of the disaster. However, there are still some problems including: expensive equipment to measure, analyze and monitor the incident so that not many installed in Indonesia, especially in areas that really need the equipment [3].

Landslide detection is generally a complex measurement, since landslides have several parameters that need to be reviewed. In addition, the landslide detection system is usually equipped with a wireless communication system, wireless communication system is used because of landslide-prone areas is an area that is not possible to build a complete system there, if a complex system built on landslide prone areas then the cost calculation for the detection system landslides are inefficient [4]. Several countries have undertaken various types of research on a system suitable for landslide mitigation. The condition of the area also affects against landslide detection study, because different regions then landslide parameters can also be different.

2. Methods

Landslide simulation is done by making landslide modeling that has a size of 200 cm x 100 cm x 150 cm with a landslide slope of 30 °. The plot is made of a mixture of sand, clay, humus soil, compost and gravel. The trigger of the landslide using the splash of water from the pipe system created so that the splash of water looks like rain. This landslide simulation will measure several parameters of landslide that is: soil shift, soil moisture and the slope of the soil. This system uses five sensors controlled by Arduino and connected to a computer via radio communications. The five sensors are: extensometer and ultrasonic sensor to measure ground shift, accelerometer to measure the slope of the soil, humidity sensor to measure moisture content, and limit switches mounted on the containment railing for alarm triggers as the last safeguard. The simulation is tuned to a different level of water based on the volume of water and simulations are done one day with the assumption that the intensity of rain every day increases. In the first simulation used water with a volume of 10 liters and increased 10 liters for the next simulation. The warning form of the system consists of three levels: ALERT for shifting the soil > 2 cm, DANGER accompanied by a puny alarm when the soil has shifted > 4 cm, and IMMEDIATELY EVACUATION accompanied by a siren sound alert when the ground has reached the hedge railing. The containment fence is the last defense before the soil is able to reach the settlement so that when the siren sounds the people can be evacuated to a safe place with valuable items that can be carried.

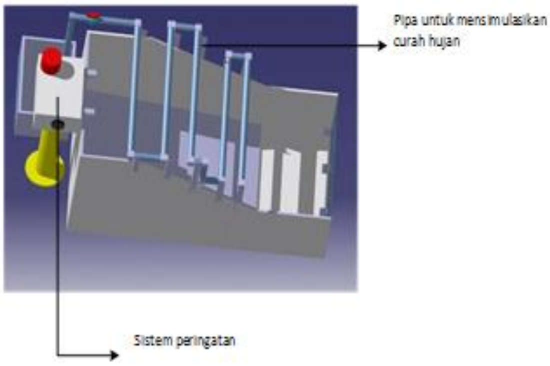

Figure 1. Design of landslide early warning model.

Figure 2. Early detection models of landslides and sensors used for monitoring systems.

The landslide model also features a portable tipping bucket rainfall meter and can record daily rain gauge. This rainfall gauge does not have to be connected to the computer because the data can be stored automatically on the memory card (SD Card) complete with rainfall time data because it is equipped with RTC (Real Time Clock). This instrument was developed initially with the aim as an alternative to an economical instrumentation system. During this, BMKG usually buy similar instruments from other countries with a price much more expensive than the cost of production of rain gauge in this study.

The rainfall gauge in this research uses the working principle of tipping bucket by using photo interrupter sensor. Made from lightweight, economical materials such as acrylic and aluminum, the instrument weighs 2.4 kg with a mouthpiece of 314 cm2 and a volume of 7.8 ml for each tipping. Rain water will enter through the mouth of the funnel and then will flow into the tipping and will move the jungkitan because of differences in weight. The juxtaposition will be counted by the sensor and the data will be processed by the arduino then stored on the memory card according to the time of the rain event. The test is done at BMKG Juanda Surabaya and all data retrieval procedures follow the rules applicable in BMKG environment. The laying of the mouth of the funnel is 120 cm from the ground and the area above the apparatus must be open at least 45 ° from the center line of the gauge. Checking the data is done in accordance with BMKG schedule at 07.00 WIB.

Figure 3. Rain gauge when being tested at BMKG Juanda

3. Results and Discussion

3.1. Testing of landslide model along with monitoring and warning system

The result of the landslide simulation conducted in 8 days with increased water volume indicates that the most easily avalanche parameter to be observed and used as warning reference is ground shift. The data in Table 1 is the simulation result obtained from each sensor used.

Table 1. Data of landslide detection system.

Tanggal	Volume air (Liter)	ADC Kelembaban Tanah	Kemiringan Tanah (°)	Pergeseran tanah dengan Ekstensometer (cm)	Pergeseran tanah dengan Ultrasonik (cm)
11/07/2016	10	130,9	0,0	0,0	0,0
12/07/2016	20	129,2	0,0	0,1	0,0
13/07/2016	30	129,9	10,6	0,3	0,0
14/07/2016	40	129,3	17,2	1,0	0,8
15/07/2016	50	129,0	17,5	1,9	1,4
16/07/2016	60	129,1	34,5	3,6	3,0
17/07/2016	70	129,0	68,5	5,3	4,3
18/07/2016	80	129,0	84,0	6,7	6,0

In accordance with the data contained in the table, the soil moisture sensor shows a continuously decreasing ADC value indicating that the moisture content contained in the soil increasingly increases as water volume increases. While the value of the degree of slope of the soil from the accelerometer data shows a significant change every day. Accelerometer in addition to function to show the slope of the soil relative to the laying of the sensor can also be used as a determinant of the direction of land shift so it can be predicted where the mass of the ground will move. However, due to the limitations of the simulation performed the function has not been used considering the direction of movement of the land will only lead in one direction only.

The use of two proximity sensors, namely the extensometer and ultrasonic aims to obtain which sensor comparators are more suitable and efficient to use. From the results obtained shows that the extensometer is more sensitive than ultrasonic. The first warning appears on the sixth day when the ground moves more than 2 cm then on the observer's computer screen will appear ALERT status. While on the seventh day the alarm and the status of DANGER have been active because the soil has shifted more than 4 cm. On the eighth day when water was poured down 80 liters, sirens and IMMEDIATELY EVACUATION status had been active because the ground had already hit a backstop. From the overall simulation data, the landslide detection system as early warning is good enough with indication of active warning form as the initial design.

3.2. Testing of rain gauge

Rainfall data collection was started on March 5, 2016 until 30 April 2016. Every checking instrument and copying data from the card was always done one day one time at 07.00 WIB (West Indonesia Time). The data were directly compared to the results data from BMKG Juanda tipping bucket rain gauge [8].

Between the rainfall data from the design instrument with the result of rainfall data from BMKG shows that the result of the design instrument has been linear to the value of BMKG rainfall with the linear equation is $y = 1.0016x$. Overall, from the beginning of equipment placement in BMKG Juanda up to the last day, the amount of rainfall at that time (57 days) based on the result from BMKG noted that there are 32 days of rain with 406.4 mm rainfall while the result of the design instrument is 407, 6 mm with a difference value of 0.3%.

The rainfall values of both design instruments and BMKG have shown compatibility and similarity. That is, the difference between the design instrument and BMKG can still be tolerated. The rainfall zero graph has two meanings that on that day there is no rain at all or rain occurs but the instrument does not read it. The instrument is unable to read any rain due to the falling rainfall is smaller than the resolution of the instrument or in other words the volume of water that is captured by the seesaw is less than the minimum volume to drive the seesaw. In standard BMKG report the event is named as unmeasured rainfall (ttu) [2, 3].

4. Conclusion

The test results show that the active role of each sensor is very important role to issue warning conditions. The system works well, shown by the change value of all sensors that can be monitored directly on the computer and the system is able to issue the warning as expected. As for warning will not always be able to appear all, could be a warning "ALERT" does not appear due to sudden movement of the ground and moving in a considerable distance. To anticipate sudden and far-reaching ground movements, the containment fence will temporarily hold the ground by activating evacuation sirens. The emergence of warnings is highly dependent on the movement of the soil. Result of feasibility test of rainfall as a whole in the period of 5 March 2016 until 30 April 2016, rainfall value recorded by instrument owned by BMKG is 406,4 mm while rainfall value recorded by SD Card is 407,6 mm with value difference of 0.3%. Quantitatively the rainfall gauge result of this research has been able to match the instrument owned by BMKG which is made from Vaisala factory, Helsinki, Finland. The economic value of this research instrument is much more affordable than BMKG instruments with not too different specifications, judging by the resolution and the total weight. The hope of testing these two instruments is that they can be applied into a unified instrument that can be used as a landslide early warning system in Indonesia.

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