Practicality of wireless sensor network technique in regional landslide monitoring

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ABSTRACT

In this study, the applicability and practicality of landslide monitoring using wireless sensor network (WSN) were analyzed. A WSN system consists of a sensor node that uses the IEEE 802.14e standard to collect and transmit data, and a gateway that collects data and sends data to the monitoring server. The sensor network topology adopted a highly flexible and reliable mesh type, and three test beds were built at each location in the Seoul area. Soil moisture sensors, tension meters, inclinometers, and rain gauges were installed on each test bed and sensor node to monitor the landslide. Sensitivity assessments for landslide, forest density and topography analysis were performed for the deployment of sensor nodes. As a result, measurements of volumetric water content, and matric suction were similar to soil water characteristic curves estimated from laboratory tests. As such, WSN monitoring system can be applicable to landslide monitoring.

1 INTRODUCTION

Recently, due to climate change, localized heavy rainfall frequently occurs and rainfall patterns are changing. Especially, landslides occur in urban areas, resulting in loss of lives and property (Kim et al. 2012; Jeong et al. 2015). The occurrence of rainfall-induced landslides is increasing internationally (Borga et al. 2002; Lee et al. 2009; Liao et al. 2011; Kim et al. 2012), and the scale of landslides is also increasing (Song et al. 2013; Kim et al. 2017). In general, steep slope landslide monitoring is planned to perform precise measurement by installing inclinometers, water level meter, and surface extensometers on representative slope section. However, in the case of landslide measurement, mountainous area other than artificial slopes have been classified as ungauged areas since the target area is usually wide and equipment entry, installation and maintenance are difficult. In order to overcome these disadvantages, several studies on the landslide monitoring based on wireless sensor network (WSN) technology are being conducted (Ramesh 2014; Zhang et al. 2017). WSN-based measurement systems can monitor regional areas by relatively low cost, but it is pointed out that long-term monitoring cannot be performed due to power problems. Recently, research on the development of sensor and routing protocol technology with low power consumption and long lifetime has been conducted (Nasseri et al. 2017). In this study, the applicability of the latest WSN technology to landslide monitoring and the design and application method through test-bed based test measurement were proposed.

2 WIRELESS SENSOR NETWORK SYSTEM

WSN is a network that analyzes various data related to the physical state measured by sensors and wirelessly transmits them. WSN generally includes sensor node, gateway of base station and client as shown in Figure 1 (Jeong et al. 2018).
2.1 Sensor node

The wireless sensor node transforms the analog data collected from the sensor into digital data with engineering meaning and transmit the data to the gateway. In this study, a wireless sensor network chipset conforming to IEEE 802.15.4e standard is applied. The sensor node consists of a microcontroller that receives analog signals, a wireless transceiver, a power supply, and a power management module. The sensor node can form a network through the self-organizing function with any node located close inside of the monitoring area.

2.2 Gateway

The gateway that collects the measurement data of the sensor node and transmits the processed data to the final server uses the wireless communication module for data transmission. In general, LTE, Bluetooth and Zigbee are the wireless communication modules installed in the sensor. In this study, LTE module was applied. For LTE security, when the IP of the gateway is changed, it is communicated with the data server. For LTE security, when the IP of the gateway is changed, it is communicated with the data server. Finally, it is possible to control the data collection of each sensor node by connecting to the gateway.

3 LANDSLIDE MONITORING

3.1 Test-beds

Three sites in the Seoul area were planned as test beds for monitoring urban landslides as shown in Figure 2. TB-1, TB-2, and TB-3 were finally selected for three representative watersheds with high possibility of landslides in consideration of past landslide and landslide occurrence history.
3.2 Landslide monitoring in the test-beds

The rainfall-induced landslide is known to be related to the temporal groundwater called wetting front due to rainfall infiltration near the ground surface, the groundwater level in the area where the groundwater is concentrated, and the occurrence of landslide due to rainfall infiltration is closely related to the antecedent rainfall, cumulative rainfall and time rainfall (Jeong et al. 2014; Kim et al. 2017; Hong et al. 2018). Therefore, in order to predict the rainfall-induced landslide, it is important to know the change of matric suction and water content of soil due to rainfall infiltration along with cumulative rainfall. In addition, it is important to measure the surface displacements in order to directly identify landslides. In this study, rainfall gauges, tensiometers (matric suction measurements), soil moisture sensors, and inclinometers (displacement measurements) were selected as instruments. One base station was installed in each test bed, and ten sensor nodes were connected to the base station. For each sensor node, one inclinometer, one tensiometer, and two soil moisture sensors were installed. One rainfall gauge was installed on each test site. Figure 3 shows the outline of the installation of each sensor node.

Figure 2 Map of three test-beds in Seoul, South Korea

Figure 3 Outline of the installation of sensor node
3.3 Monitoring results

Measurements were carried out from the beginning of the dry season to the wet season, and it was confirmed that the water content increased suddenly as rainfall penetrated into the ground as shown in Figure 4. Figure 5 shows the maximum and minimum matric suction of each test-beds measured during the dry season and the wet season. In rainy season, the matric suction was measured to be about 0.2 ~ 7 kPa, which was in the range of values measured in unsaturated or saturated soil. The maximum matric suction was measured at the dry period of 45 ~ 50 kPa, which is the general range of the silty sand layer as the upper soil layer of the test-beds of this study. In TB-1, however, the matric suction was about 20 kPa during dry season, which was analyzed by the effect of perched water on the TB-1 developed rainwater permeable layer. In fact, boring and excavation conducted at TB-1 revealed groundwater levels of around 2 m. Also, as shown in Figure 6, in-situ soil water characteristic curve (SWCC) was estimated by measuring the matric suction and the water content which are temporally and spatially identical, and then the SWCC of the site was compared with the SWCC of soil estimated from the laboratory test. The monitoring result in the field has a good agreement with the laboratory test result. However, the volumetric water content is slightly lower than that of the laboratory test result when the matric suction is more than 10 kPa. That’s because the result of the field measurement can be distinguished as the wetting path and the laboratory test were measured in the drying path.

![Figure 4: Field measured volumetric water contents of soil](image-url)
4 CONCLUSIONS

In this study, test-beds based study was conducted to confirm the applicability of WSN to landslides monitoring. WSN system was constructed to detect landslide characteristics, and data were collected from the soil moisture sensors and tensiometers installed at each sensor node, and the responses of the ground by rainfall were analyzed. The results of the study are summarized as follows:

(1) The WSN measurement system for landslide monitoring uses a self-configuring mesh topology and a time synchronization mesh protocol of the dust network so that each sensor node can operate at low power in
consideration of communication environment. As a result, an efficient and flexible deployment and a good network connection were satisfied.

(2) The analysis of the measured data at three test beds TB-1, TB-2 and TB-3 showed that the response of the ground due to rainfall was similar to that measured at laboratory tests. In addition, the volumetric water content increased from 0 ~ 0.15 to 0.2 ~ 0.45 as the rainfall changed from the dry season to the wet season. The measurement results showed that the matric suction decreased from 0.2 to 7 kPa at 30 ~ 50 kPa.

(3) In this study, we obtained relatively good quality data from the WSN system and confirmed that it is possible to apply the WSN for landslide monitoring in the field.

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