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EARLY WARNING SYSTEM FOR RAINFALL INDUCED LANDSLIDES

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Abstract

This project proposes and implements an early warning system for rainfall-induced landslide (named as EWRIL) with case study at the Kerala landslides. The proposed system consists of six sensor nodes and one rainfall station that are used to sense large amounts of data in real-time such as soil moisture, pore-water pressure (PWP), movement status, and rainfall. These methods are available in the SEEP/W and SLOPE/W modules of the Geo Studio software. Based on the analyzing results, the system proposed three warning levels for the landslide Early, Intermediate, and Imminent. Experiment result in the rainy season from August to September has proven the validity of the EWRIL system. The result of this is useful for land slide risk Prevention and management in landslide prone-areas.

Introduction

Rainfall-induced landslide is one of the most serious natural hazard problems. Annual direct and indirect economic losses and casualties were estimated. Due to changes of climate. This problem is of particular concern in kerala, where landslides occurred in almost all mountainous areas due to high frequency of tropical rainstorms in recent years. Therefore, studying of landslides to determine measures for landslide risk prevention and management is highly necessary. These have been clearly stated in the guidelines for risk analysis and sustainable disaster management. Among various methods for the landslide risk prevention, monitoring and early warning systems are considered to be one of the most promising ways. Literature review shows that various monitoring and early warning systems for rainfall-induced landslides have been successfully proposed, from national to site-specific scale with different time spans i.e. short term, medium term, or long term. For national and regional scales, early warning systems are built mainly based on the established relationships between rainfall intensity/duration and the consequent activation of landslides. However, monitoring of only rainfall for evaluating the failure for individual slopes is not enough because the shear strength of these slope materials is not always the same.

Background of the methods, sensors, and wireless networks used

To implement a rainfall-induced landslide warning system, it is necessary to determine the instability status for the landslide being considered, and for site- specific landslides, the instability status can be determined using factor of safety). Thus, FoS could be monitored and assessed using wireless sensors network and Geo Studio software installed in a monitored station. This section describes the theoretical background of FOS, the software used for calculating FOS, and the proposed wireless sensors network used.

Sensor and wireless networks for rainfall-induced landslide early warning system

The successful design and implementation of a rainfall-induced landslide early warning system are strongly dependent on sensors and networks used. The reason is that the sensors and networks are used to collect, handle, and transmit massive amounts of monitoring data Therefore, it is necessary to properly determine type of the sensors used, number and location of the monitoring points, and sampling rates of the monitored parameters. It is well-known that the selection of the sensors is dependent on triggering parameters of the landslide being considered. For rainfall-induced landslides, failures are mainly influenced by groundwater condition, rainfall intensities, and soil properties of the slope. Accordingly, infiltration of water into the slope material during rainfall events causes increasing PWP and decreasing shear strength, and thus, reducing the FoS. Therefore, PWP sensor and soil moisture sensor should be used to collect and monitor the material characteristics of the slope for determining the instability status of the land slide.

Soil moisture sensor:

One of the most important factors affecting the infiltration of soil is the amount of water. In unsaturated soils, the volume of water stored within the void spaces is varied, depending on the matric suction within the pore-water. The metric suction is defined as the difference between the air (and water pressure, Therefore, the soil moisture sensor should be used to gather the volume of water in the soil. Accordingly, the volume of water content is derived indirectly through measuring the electrical conductivity of the soil medium surrounding them using the following equation where SM is the soil moisture value (%); SMADC is the analog to digital converter (ADC) output; and OSADC is the offset value at 0Kpa.

Wireless communication:

In this study, we proposed to use XBee-Pro ZigBee module (also called XBee for short) that is based on the wireless communication and is engineered for operating with the ZigBee protocol. The main advantage of ZigBee is that it consumes low power; therefore, it is suitable for the sensor nodes powered by battery. The XBee module has a data rate up to 250 kbps with the 2.4 GHz ISM band. Furthermore, the XBee module includes low power sleep mode.

Microprocessor:

This is a central element of a sensor node. The microprocessor controls sampling time, collects data from sensors, conveys aggregate data to the Radio Frequency (RF) module to transmit to the sink node. In these sensor nodes, where power consumption is constrained by battery capacity, the microprocessors should be low power consumption.

WSN:

This is proposed for the Rainfall- Induced Landslide Early Warning and Monitoring System because it has proven suitable for applications in environmental monitoring due to its flexibility, real-time data capture, and transmission. In this study, the WSN consists of six sensor nodes and one sink node. Environment parameters are measured at these sensor nodes, and then, are transferred to the sink node via wireless links. The sink node delivers the measured data to users through internet by a gateway. The proposed EWMRIL

Structure of the proposed early warning and monitoring system

The structure of the proposed EWMRIL in this study. First, the microprocessor units in these sensor nodes acquire the data from all sensors and transfer to the wireless interface module, and then, the wireless interface modules send the data to the sink node and the gateway unit. In the next step, the data are uploaded to the Web Server through the gateway. Then, the data from Web Server are formatted and forwarded to the monitoring Website, the mobile phones of people in charge, and the Computer Station. Finally, the Geo Studio program at the Computer Station is used to analyze the instability status (using FoS) of the slope being considered, and its results can be used to reconfigure the WSN and give an alarm if need be.

The rain gauge and computer station

In this system, a rain gauge is additionally proposed to the system to measure the rain precipitation over a set period of time. The real-time measured data from the rain gauge are transferred to the Geo Studio software at the computer station to model the PWP distribution in the soil slope. Using the SEEP/W module, the flow of water through the unsaturated soil was estimated by using the Darcy's Law and Equation 1. In addition, WSN software that is developed by the authors is installed at the sink node for the EWMRIL system. This WSN software consists of three modules, data acquisition, data processing, and data communication. The first one is used to record monitoring data from the sensor nodes. The second one is the core component module of the software and is used to process all the incoming monitoring data, and then, sends the command to the sensor nodes. The final module provides the routing algorithms and time synchronization method.

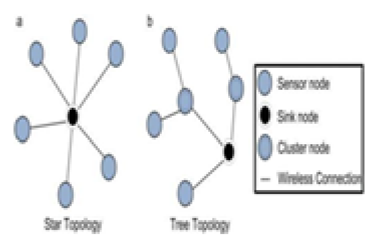

Figure 1 Network topologies used in this study

Proposed working principle

Due to the focus of the presented study is on rainfall-induced landslides, the monitoring data are collected and recorded

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mainly during and after rainfall for saving the energy of the EWMRIL system. In addition, different operating scenarios are also proposed based on rainfall scenarios and corresponding FoSs. More specifically, we defined the two operating scenarios, warning mode and normal mode, based on thresholds computed through an analysis of rainfall and its duration for the slope being considered.

Proposed working principle for the instability prediction and the real-time warning

The proposed working principle of the instability prediction and the real-time warning is shown in Figure 5. Threshold_0 is an empirical pre-set value of rainfall intensity. In our work, Threshold_0 is determined based on the formula if the rainfall reaches this threshold, the system will send a notification to the operating expert suggesting that slope stability analysis should be performed. If the rainfall intensity is lower than Threshold_0, the operation of this.

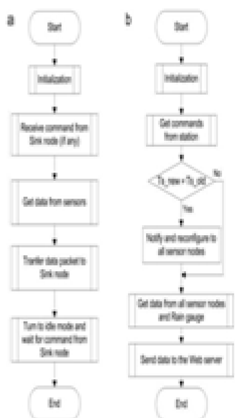

Figure 2 the proposed working principle in this research: (a) the wireless sensor nodes and (b) the sink node and gateway unit.

The system depends on its current operating status, in the warning state or not. For example, although the rainfall intensity is lower than the threshold_0, the slope is in an unstable state because of high PWP, the system will send a notification to the operating expert. If the slope is in stability status and the rainfall intensity is below Threshold_0, there is no need to evaluate the landslide hazard. It should be noted that the warning state is a binary variable, '1'—warning state, whereas '0'– safe state. The value of this variable defaults to 0 and would be set to 1 (if FoS< = Threshold_1) or 0 (if FoS> Threshold_1) after analyzing the slope stability.

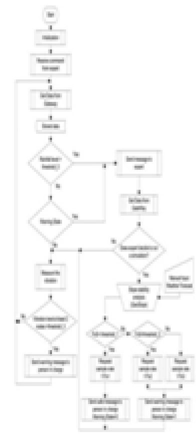

Figure 3 the working principle of the proposed system.

Thus, if the slope is predicted as unstable, the sensors will switch to the higher sampling rate, and vice versa, if FoS is higher than Threshold_1, the system will switch to the normal state, in which the sample rate used is lower to reduce the power consumption of the sensor nodes. Based on FoS, the computer station will send a message to the sensor nodes. If FoS > Threshold_1 (the slope is in a safe state, the weather is good, and the pore-water pressure is low), the WSN will switch to tree topology mode. In this mode, the pre- defined sensor nodes will be changed to the router mode. The other sensor nodes are used as the end devices and they will connect to the sink node through the router.

Data collection and processing

In this research, four laboratory tests, the physical properties test, the pressure plate test, the direct shear test, and the triaxial test were conducted to acquire physical and mechanical parameters for each layer. In addition, the parameter of residual strength of soil was determined. These samples were then analyzed at the geotechnical laboratory to determine geotechnical properties such as soil classification, water content, soil–water characteristic curves, and shear strength.

Figure 4 Location of Kerala land slide.

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It is noted that the Unified Soil Classification System. Using the four laboratory tests mentioned. These geotechnical properties of the slope were then used to calculate FoS using the SEEP/W and SLOPE/W modules in the Geo Studio software.

Concluding remark

This paper proposed and implemented a EWMRIL with a case study at Kerala landslide explanation of the technical design of the EWMRIL system is provided. According to current literature, such kind of an explanation has seldom been provided. Therefore, the work could partially fill this shortage in literature. The proposed EWMRIL is an integrated system that combines a wireless sensor network, the FES analysis, and the limit equilibrium slope stability analysis for a real-time early warning and monitoring of the landslide. Accordingly, the instability status of the slope was determined based on FoS that was calculated using its parameters derived in the fieldwork. These parameters are monitored real time and sent to the computer station to compute FoS. Based on the computed FoS, the status of the slope was analyzed, and then, decision-making could be issued. The advantage of the proposed system is that flexible and reliable WSN are introduced to adapt to the designed warning state of the landslide. Consequently, the system is more balanced between the power saving and the reliability.

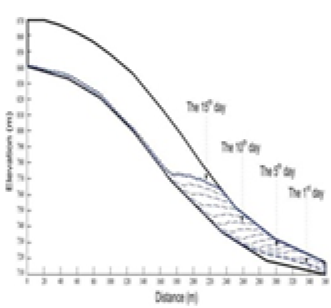

Figure 5 Seepage estimation

The tree topology to the star topology when the rainfall reaches to the determined threshold. In our work, the WSN system only switches from the tree topology to the star topology when FoS reaches to a warning threshold. Thus, the proposed system in this research is more effective than that in the previous works, One of the critical problems in an EWMRIL land slide is that some sensor nodes buried in the slope may be broken or destroyed or out of work due to the moving of the landslide or other errors, therefore, reducing the reliability of the system. In this study, the proposed system is capable to automatically switch from the tree topology to the star topology when the slope is in unstable status. Therefore, if some sensor nodes are broken, the other sensor nodes will continue working, and thus, the reliability of the system could be preserved. Besides the proposed flexible configuration of the system, a new working principle for the wireless sensor nodes and the gateway has also been proposed. Accordingly, two operating scenarios, the warning mode with the designed high sampling rate and the normal mode with the designed low sampling rate, therefore, the power consumption is lower than that at the regular working principle.

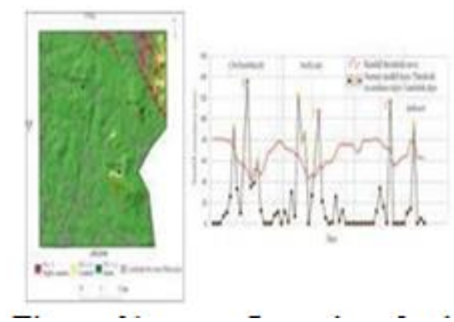

Figure 6Average Intensity of rainfall

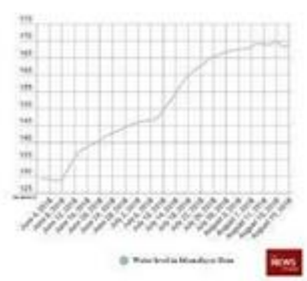

Figure 7 Intensity of rainfall

The main limitation of the proposed system in this work is that the EWMRIL system is feasible for site-scale rainfall- induced landslides. In addition, the system requires a detailed geotechnical investigation to establish FoS, therefore, this may be a cost-consuming system, especially for large landslides. Furthermore, due to the natural limitation of the current sensor and wireless technology in terms of power consumption, more power-efficient solutions should be further considered in the future to improve the EWMRIL system.

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At the final conclusion, despite some aforementioned limitations, the result of this research is useful for landslide risk prevention and management in landslide prone-areas.

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