Analysis of Rainfall Induced Slope Disaster and Development of Early Warning System based on IoT

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https://hdl.handle.net/2324/5068203

出版情報：Kyushu University, 2022, 博士（工学）, 課程博士
バージョン：
権利関係：

（様式２）

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論 文 名　：Analysis of Rainfall Induced Slope Disaster and Development of Early Warning System based on IoT
(降雨による斜面災害の分析および IoT を活用した早期警報システムの開発)

区　　分　：甲

論 文 内 容 の 要 旨

With changing global weather patterns, the occurrences of unpredictable heavy rainfall have increased leading to more frequent rainfall-induced landslide disasters. It has been reported that the number of rainfall-induced landslides in Japan has increased by 50% compared to the last 10 years. Landslides triggered by rainfall pose a tremendous threat to life and property. Therefore, many researchers have been engaged in analyzing the stability of slopes and mitigating such disaster problems. On comparing different methods, such as hard types, numerical simulations, and monitoring methods, it was found that the application of an early warning system (EWS) based on real-time data and slope stability assessment is a practical approach to mitigating such disasters. However, the existing EWS has some obvious shortcomings, such as the high cost of equipment and high power consumption, which makes it impossible to be widely applied and achieve the SDGs. In addition, the lack of effective assessment indices in the system leads to inaccurate early warnings. In addition, the existing systems are usually industrially manufactured, making it difficult for users to change or upgrade the hardware or software architecture.

To develop an effective EWS that is consistent with the goal of the SDGs, a cost-effective and sustainable EWS that integrates the Internet of Things (IoT) and a solar-powered integrated platform for data collection, transmission, and analysis is presented. To improve the prediction accuracy, rainfall-induced slope failure analysis to obtain the real-time safety factor, and proposed evaluation indices from various precursor phenomena of slope failure based on motion analysis and interpolation analysis are conducted in this research.

For the slope stability analysis, the Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability (TRIGRS) model was used to analyze the failure of the shallow slope, while the upper bound analysis was used to obtain the critical safety state of the failure of the deep slope. For the development of the EWS, all the sensors used in this system, such as the soil moisture sensor, the pore water pressure sensor and the 9-axis accelerometer, are low cost and portable. Based on the principle of rainwater infiltration and the movement of soil particles, important warning indices were established in the system. Three levels of landslide risk classification were also proposed. For the model test, this study considered two influencing parameters: initial moisture content and rainfall intensity. This study revealed the infiltration process of the sandy slope, captured the ground motion by motion analysis, and extended the limited experimental data to a global analysis by interpolation methods.

The main contributions of each chapter in the dissertation are as follows:

Chapter 1 presents the background, methodology, objective, and original contributions of this study. It highlights the threat that rainfall-related disasters pose to the social economy and the lives of residents. It compares current approaches to disaster mitigation and suggests that EWS is an effective and appropriate approach. This chapter presents the improvement points of current IoT-based EWS and highlights the significance of this study for disaster mitigation.

Chapter 2 reveals the potential forms of slope failure under rainfall conditions. For shallow failure conditions, TRIGRS model was used for stability analysis. For deep failure mode, upper bound limit analysis was used. A series of illustrations presented the Fs of slope under different soil parameters and rainwater infiltration conditions. The results imply that Fs decreases significantly due to the influence of rainfall infiltration, while the effect of suction in an unsaturated state can improve the stability. Furthermore, the safety assessment results can be used as important indicators for early warning work.

Chapter 3 presents the composition of the EWS in detail, including the software aspects for receiving, transmitting, and processing data. The hardware aspect includes sensors, communication devices, Wi-Fi router, solar battery system etc. This chapter also presents the monitoring process, risk determination, and timing of signal transmission. This part of the thesis forms the basis for experimental verification and field application.

Chapter 4 presents the performance of the EWS during model tests. It presents the test conditions, sensor arrangement, and model test setup. It shows in detail the evolutionary trend of soil moisture content, pore water pressure, deflection angle, and real-time Fs in each test. It defines key warning indices and divides the risk levels according to the principle of the EWS. The proposed landslide risk classification divides the whole process into three stages: Initial Monitoring State, Alert State, and Triggering State to issue alerts. The accurate testing results conducted on sandy slopes enable us to identify the risk stages, send warning signals, and predict potential movements so that people near the danger zones have enough time to escape and isolate the area.

Chapter 5 provides the study of the experimental data from the motion analysis and interpolation method. Two groups with different rainfall intensities and initial moisture contents were considered. The motion analysis is based on computer vision-based monitoring technology, which can track extremely small displacement, particle trajectories and velocity. Results provided an indication of the potential trajectory and movement characteristics when a landslide occurs in reality. The interpolation method was used to predict the intermediate data for training the EWS model for a wide range of meteorological conditions. It also helps predict the sensor data for blind areas where sensors could not be placed. Accurate interpolation results can help the EWS provide potential risk levels for larger areas and more rainfall conditions.

Chapter 6 summarizes all the contributions and introduces future research.