Estimation of spatial soil distribution changed by debris flow using the topography restoration method

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1. Introduction

To survey debris flow has been a growing emphasis on field surveys as well as on remote sensing and GIS. This is due to a difficulty accessing the location of debris flow occurrences and the considerable amount of time and cost required to gain access to the locations. In airborne Lidar surveying, Lidar pulses can penetrate tree crown, thereby solving the problem of tree branches and trunks blocking the signal. Lidar surveying offers 3-dimensional topographical information far more precise and accurate than data obtained from the popular satellite imagery and aerial photography. Aerial Lidar surveying also has expanded the realm of mostly 2-dimensional debris flow research, into a 3-dimensional endeavor offering effective databases that researchers can use to trace a series of mechanisms, in which a debris flow occurrence takes place and soil sediments are transported and deposited. The surveying technique can also help estimate changes in the volume of soil. Topographical data by Lidar are useful and are applicable in many related fields; they are used in verifying various physical models of debris flow and as reference materials required for designing debris flow barriers, as soil volume data for debris flow hazard maps, and as data for forecasting secondary effects of floods. To obtain 3-dimensional data on debris flow using aerial Lidar surveying, topographical data surveyed before and after the debris flow occurrence must first be available. However, rendering accurate forecasts on locations where a debris flow occurrence took place is a challenge. Moreover, surveying a given area in advance with high likelihood of having a debris flow occurrence is practically difficult. Woo(2011)* developed a method for restoring topographic contours of a terrain prior to a debris flow occurrence by using aerial Lidar data obtained after an occurrence (here in after referred to as "the topography restoration method"). The method was used in this study to restore the pre-occurrence topographic contours in three South Korean locations, namely Inje county in Gangwon province, Bonghwa County in North Gyeongsang province, and Jecheon city in North Chungcheong province. The data were then used to analyze the distribution of soil altered by debris flow occurrences that had occurred in the areas. In addition, the spatial distribution of erosion, sediment transport and sedimentation that take place over the course of a debris flow occurrence, and the actual volume of soil transported down the river were calculated based on the topographic data.

2. Materials and Methods

2.1 Theoretical Study of the Topography Restoration Method

The topography restoration method proposed by Woo(2011)* is a technique that produces high-precision data on the topographic contours before a debris flow occurrence by using aerial Lidar data. The data is obtained after the debris flow occurrences in order to estimate the amount of soil loss resulting from the flow occurrence. Woo's method comprises five steps as shown in Figure 1. First, researchers use a DEM (Digital Elevation Model) created from the aerial Lidar data that classify terrain point data into categories. They then use the information to detect the area wherein a debris flow occurred and extract cross sections at regular intervals. This step is followed by the estimation of central position in the extracted cross sections, and then by the use of a Gaussian mixture model on the cross sections to estimate the optimal topography of the terrain in which the debris flow had occurred. Accuracy of the restored topography was based on the RMSE of ±0.5m for 1m DEM and a maximum error of ±0.75m as the reference value. The Gaussian mixture model is listed in Equation 1. The model offers benefits, including the description of distribution characteristics that cannot be expressed with a single Gaussian distribution, and the accurate approximation of even a complicated distribution with the use of enough Gaussian functions.

$$f(x) = \sum_{i=1}^{n} a_i \, exp\left(-\left(\frac{x-b_i}{c_i}\right)^2\right) \quad \text{(Equation 1)}$$

2.2 How to analyze spatial distribution of soil variation

In the spatial distribution of soil variations, the vertical error of the LIDAR data (±0.25 m) was used as the critical value to define the plus section and the minus section as sedimentation and erosion, respectively, and the critical section as debris flow (movement) section. This section-specific distribution offers a benefit that one can easily understand how the actual debris flow was developed and how it changed the terrain, and thus it is believed to help researchers study the debris flow mechanism. Distribution of sediment transport refers to the division of soil-volume distribution at certain intervals and the analysis of accumulated amount of soil. Sediment-transport distribution enables researchers to estimate how much of soil has actually been transported toward the alluvial fan, which is affected by debris flow occurrences as erosion and sedimentation are accumulated as a result of soils moving downstream. The information is extremely useful in that it helps figure out the dimension and location of debris flow barriers

3. Results and Discussion

As a result of applying the topography restoration method, the RMSE for Inje was found to range between 0.03 and 1.33 (Figure 5), with the mean RMSE of 0.34. In Bonghwa, the RMSE ranged between 0.04 and 0.36, with the mean RMSE of 0.16. The RMSE for Jecheon ranged between 0.02 and 0.51, with the mean RMSE of 0.16. The mean RMSE of each area was extremely small compared with the accuracy criteria for this study. Moreover, the distribution of RMSE values showed a low tendency, which helped to verify that the majority of the approximations were accurate. The distribution of changes in soil resulting from debris flow occurrences indicates the amount of sediment transport caused by the occurrences and was produced as soil volume distribution, section-specific distribution and sediment transport distribution, depending on the purpose. The analysis was performed by using the pre-occurrence topographical data created by the topography restoration method and the post-occurrence topographical data.

The soil volume distribution refers to the amount of soil that has been altered, and it allows for the estimation of soil volume variations in each space. The distribution map was produced based on the difference in topographical data that indicate the pre- and post-occurrence topographical contours. The '+' indicates sedimentation, while '-' indicates slope-failure (erosion). A soil volume distribution offers extremely useful information that is used in the estimation of the cost and scale of rehabilitating damages. It is also used as valuable information for researchers in their effort to forecast debris flow occurrences and prevent damages from them. The section-specific distribution shows three types of the debris flow mechanism, namely slope-failure (erosion), transport and sedimentation. The sediment transport distribution denotes the accumulated amount of sediments resulting from soil transport. The distribution allows the estimation of the intensity of debris flows that vary with spaces, as well as the estimation of the amount of direct soil transport downstream. The distribution offers benefits that the amount of sediment transport downstream can be identified even if sediments accumulated downstream were cleared by emergency rehabilitation. The comparison between the amount of soil in each area and the amount of daily sediment transport revealed that in Inje, 200㎥ of sediment was produced at a site of debris flow, and that erosion and sedimentation were repeated in a 800-m long section until about soils of 10,000 ㎥ were transported downstream. In Bonghwa, four sites of debris flow produced 490㎥ of soils which repeatedly underwent erosion and sedimentation in a 580m long section until about 2,600㎥ of sediments were transported downstream. As for Jecheon, 700㎥ of soils were produced from eight sites, which repeated the process of erosion and sedimentation in a 850m long section until about 8,000 ㎥ of sediments were transported downstream. The amount of sediments transported downstream daily was approximately five to 50 times the amount of soils produced from landslides.

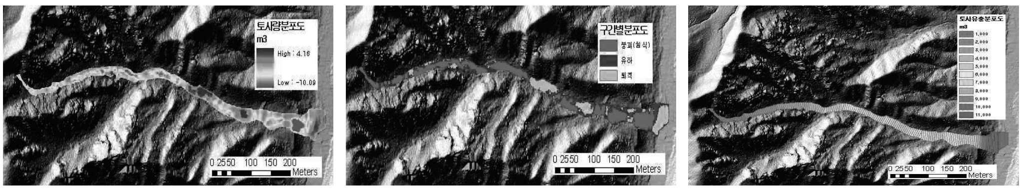

Figure 1. The spatial soil distribution changed by debris flow is comprised of three types -the soil volume(left), the section(middle), the accumulation(right) in Inje county

* Woo, C., 2011. The aerial LIDAR surveying-based development of the method for restoring the topography of areas affected by debris flow occurrences. Doctoral dissertation, Inha university.