Computers & Geosciences 70 (2014) 238–247

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

MATLAB code to estimate landslide volume from single remote sensed image using genetic algorithm and imagery similarity measurement

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ARTICLE INFO

Article history:
Received 9 December 2013
Received in revised form
7 May 2014
Accepted 9 June 2014
Available online 23 June 2014

Keywords:
Remote sensing
Image correlation
Topographic relief
Terrain change
Genetic algorithm

ABSTRACT

Information regarding the scale of a hazard is crucial for the evaluation of its associated impact. Quantitative analysis of landslide volume immediately following the event can offer better understanding and control of contributory factors and their relative importance. Such information cannot be gathered for each landslide event, owing to limitations in obtaining useable raw data and the necessary procedures of each applied technology. Empirical rules are often used to predict volume change, but the resulting accuracy is very low. Traditional methods use photogrammetry or light detection and ranging (LiDAR) to produce a post-event digital terrain model (DTM). These methods are both costly and time-intensive. This study presents a technique to estimate terrain change volumes quickly and easily, not only reducing waiting time but also offering results with less than 25% error. A genetic algorithm (GA) programmed MATLAB is used to intelligently predict the elevation change for each pixel of an image. This deviation from the pre-event DTM becomes a candidate for the post-event DTM. Thus, each changed DTM is converted into a shadow relief image and compared with a single post-event remotely sensed image for similarity ranking. The candidates ranked in the top two thirds are retained as parent chromosomes to produce offspring in the next generation according to the rules of GAs. When the highest similarity index reaches 0.75, the DTM corresponding to that hillshade image is taken as the calculated post-event DTM. As an example, a pit with known volume is removed from a flat, inclined plane to demonstrate the theoretical capability of the code. The method is able to rapidly estimate the volume of terrain change within an error of 25%, without the delays involved in obtaining stereo image pairs, or the need for ground control points (GCPs) or professional photogrammetry software.

1. Introduction

Landslides may be induced by rainfall, earthquakes, or a combination of these two factors, and the distribution of landslide phenomena can be characterized both temporally and spatially. More than 64 factors with various weightings were reported to affect the probability of a landslide occurring (Koukis and Ziourkas, 1991). Landslide susceptibility assessment relies on all forms of spatial data and a geographic information system (GIS) to find corresponding factors and weighing indexes for the examined event (van Westen et al., 2008). Once the combination of these indexes and factors is able to account for the most common landslide event, thus a landslide model is produced. Adaptation of this general model to a specific region requires testing and refinement. The ideal scenario is to alter only one factor at a time, such that the referenced spatial data have to be adjacent to the occurring time of such event. For example, a study of a rainfall-induced landslide would require remote sensed imagery obtained immediately before and after the rainfall event. The differences between these two images can be compared via normalized difference vegetation index (NDVI) or image similarity methods (Cheng et al., 2004) to produce a distribution map of the newly changed area. This map then serves to check the output of a model that incorporates the updated rainfall factor. If the agreement between the post-event imagery and the GIS forecasting map is sufficiently high, then the influence of such factor and also its weighing index is verified. The above process should be executed for each individual factor, meaning that all the listed factors require up-to-date information for verification purposes, and also to ensure the accuracy of the model computation. Some spatial information might be easily interpolated from collected data sets, such as rainfall, Peak Ground Acceleration (PGA) of earthquake or a digital terrain model (DTM). Other types of information require additional data-handing, of which one typical example is the calculation of landslide volume.

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http://dx.doi.org/10.1016/j.cageo.2014.06.004
0098-3004/

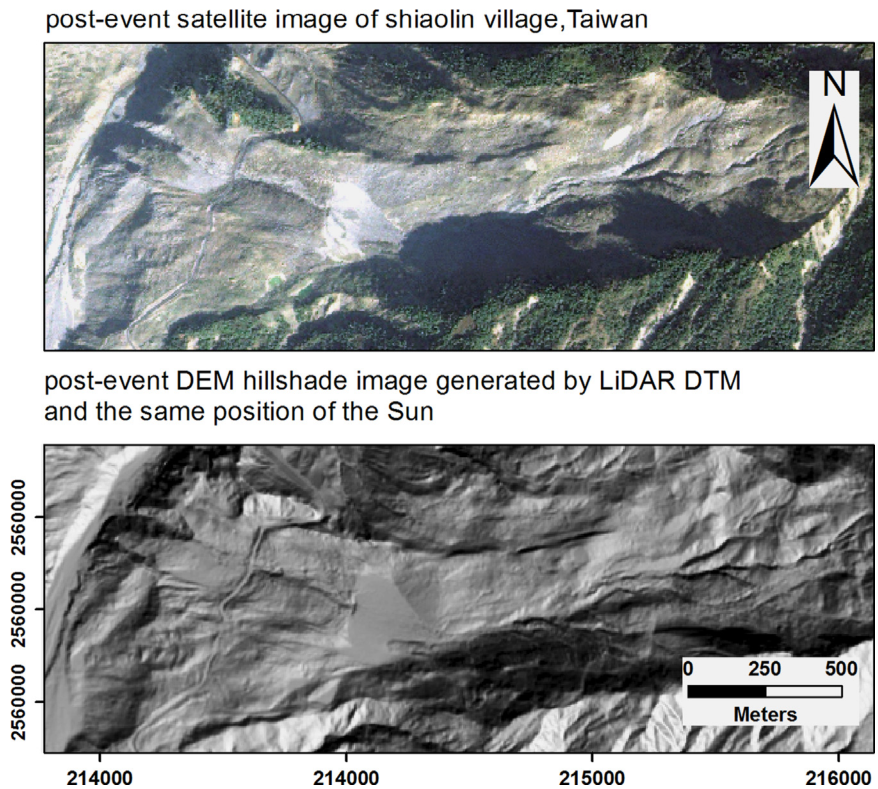

Fig. 1. Similarity between DTM hillshade and satellite image.

There are some semi-empirical methods to estimate landslide volume in the absence of surveying data. The mechanics method, proposed by Dymond et al. (1999), considers that when a landslide occurs, its shear stress is supposedly the same as the shear strength, which determines the relationship between slope angle and landslide depth. The area-to-volume method employs linear regression to analyze data from existing events in order to determine whether the area and volume of landslide are positively correlated. However, the resulting predictions show major inconsistencies between various tested areas (Brunetti et al., 2009; Guzzetti et al., 2009). The slope-to-depth method proposes that the ruptured depth of a landslide is associated with the slope angle (Iida, 1999). For seismically-induced landslides, a change of 1 foot in the failure depth leads to a change of critical acceleration by an order of seismic magnitude (Khazai and Sitar, 2000a), and the seismically ruptured depth of soil cover changes from 0.5 m to 2 m as the slope angle varies from 30° to 60°, as proposed by Khazai et al. (as cited in Wang and Lin, 2010). One disadvantage of this method is the geological characteristics of different areas, topographical or lithological structure could lead to very large errors in the estimation. Photogrammetry from optical imagery; radar interferometry; and laser ranging LiDAR via satellite, airplane, or unmanned aerial vehicle could provide multi-temporal images of landslides and produce DTMs with centimeter-level accuracy (Delacourt et al., 2007). There is no doubt about the maturity of such techniques or the accuracy of the DTMs produced. However, the associated time and budget constraints mean that such precise data are not generally collected.

To reduce the error in estimation of landslide volume and to lessen the cost of traditional surveying methods, we propose a quick, automated method to calculate the post-event DTM using a single remotely sensed image. The proposed method requires neither a pair of stereo images nor ground control points (GCP) to perform the photogrammetric calculation, and thus, it could be gathered within a few days following the event. This method involves an intelligent means by which to estimate landslide volume by ranking the similarity between the remote sensed imagery and computer-generated candidates using the principles of digital image correlation (DIC). DIC maximizes a correlation coefficient that is determined by examining pixel intensity array subsets on two or more corresponding images and extracting the deformation mapping function that relates the images. Our proposed method uses a smart algorithm to select the most appropriate shade, representing a relief image, from a vast number of computer-generated candidates. Genetic algorithms (GAs) follow the principle of natural selection; they have the capability to automatically evolve and produce the most suitable offspring. GAs have been used in medicine to classify images of the brain (Nanthagopal and Rajamony, 2013), and to recognize vehicle license plates (Awad, 2012). All archived remote sensed images could be utilized to estimate the corresponding DTMs, as long as the cover ratio of cloud and haze is less than 10%. This approach could estimate landslide volume more precisely than semi-empirical estimation methods. The availability of regular remote sensing imagery far exceeds that of stereo pairs. Standard procedures for producing DTM from remote sensed images require a certain overlap between stereo pairs and sufficient GCPs. As a result, DTMs of any hazardous region are very rare and expensive. LiDAR is able to generate a DTM with fewer GCPs and easy handling process but still requires special tools and professional skill to process the vast amount of point cloud data, not to mention the high cost of aerial LiDAR scanner and aircraft flying. All of the above limitations mean that it is unrealistic to expect useable, updated information immediately after an event. The proposed method could be used to quantitatively analyze any event occurring between the acquisition of two reference images (pre-event DTM and post-event remote sensing image). The method is able to estimate the amount and also the distribution of changes, which