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Tree stem shapes derived from TLS data as an indicator for shallow landslides

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Abstract

Landslides or other forms of mass movement influence slope stability, and are known to have significant effects on vegetation patterns. Observation of such surface patterns may result in valuable information for understanding the kinematics of the landslide. In forested regions, tree growth anomaly is often served as an indicator of shallow landslide activity. Terrestrial laser scanning (TLS) is able to acquire accurate and dense 3D point cloud which provides the potential of reconstructing forest structure. In this study, we obtained high density TLS data in the northern Walgau in the federal state of Vorarlberg in Austria, where translational mass movement phenomenon exists in a forested region. A novel algorithm was developed to fast and robustly characterize single tree parameters (e.g. diameter at breast height (DBH), inclination angleof the stem and stem volume). Consequently, these tree parameters were successfully determined at single tree level. Field measurements were conducted in order to validate the results from the modelling algorithm. The root mean square error of DBHis 1.6 cm (4.9%). The average steminclination angle is 8.2°. The results of this study revealed that characterization of trees (i.e. inclination of the stems) can be used to indicate shallow landslide activities in forested regions. The quantification of tree parameters could also contribute to a better understanding of the interaction between landslides and trees.

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1. Introduction

In mountain regions, slope instability is known to have significant effects on vegetation patterns[1].In the past decades, remote sensing techniques have been explored to map and assess landslides at regional scales[2, 3]. However, detailed above-ground vegetation characteristics on landside area are less investigated because of low density and quality of observed data. Terrestrial Laser Scanning (TLS) is able to acquire accurate and dense 3D point cloud of objects. It has been proven to be an effective tool in various environmental applications, e.g. forest research and management[4-8], monitoring in the geosciences, including landslide assessment[9], glacier monitoring[10, 11], and roughness quantification[12], but also in fields like deformation monitoring[13]and cultural heritage[14].The applicability of TLS technique provides the potential of reconstructing forest structure. Thereby, quantification of tree growth anomaly induced by landslides and soil creeping becomes feasible.

Tree growth anomaly is a phenomenon that is caused by soil movement in landslide regions[15]. However, so far in landslide researches,TLS is mainly used to monitor and quantify the displacements and deformations[16, 17]. Only a limited number of studies tried to characterize the tree growth anomalies caused by landslides[18, 19]. In Razaket al.[18], the authors evaluated the tree inclination angle using a skeleton method. However, their work involved enormousmanual delineation of single trees. Furthermore, only the inclination angle at the height of 1.3 m above ground was calculated.The lack of relevant studies calls for the development of automatic tree shape quantification approaches.

The current study focuses on the use of TLS data for quantifying tree growth anomaly in landslide-affected forests. The critical question is how to effectively detect and assess the trees in the region that is often characterized by steep terrain, dense understory, and complex stem shapes.Therefore, the objective of this paper is to present a novel algorithm for stem modellingand quantification in landslide-affected forest environments. We describe in this paper a random sample consensus (RANSAC) based robust stem reconstruction method, and a Frenet-Serret formulas based quantification method with application example for a landslide region in Austria. The purpose of this contribution is rather to discuss the general potential of using TLS data in assessing tree growth anomaly induced by shallow landslides,thus the main focus lies on the methodology, and not on geomorphological aspects.

In the following section 2 the study area and the used data are described, in section 3 the developed method is presented. Results and discussion are presented in section 4. Conclusions are given in section 5.

2. Study area and data

2.1. Study area

The study area is located in the northern Walgauin the federal state of Vorarlberg, Austria (Fig. 1), where several translational landslides exist. This small region is part of the covered study area of the project BioSLIDE (The influence of Biomass and its change on landSLIDEactivity)[20].The specific study site is inside a small forest located near the rupture surface of a shallow landslide, which is characterized by steep terrain with multi-layered canopy structure including dense understory, mixed forests, complex stem shapes and dead tree branches. Tree stems are overall curved due to the effects of soil movement. The dominating tree species are spruce, fir and European beech. Fig.2 shows the morphologic overview of the landslide in the investigated area. Water crop-outs from the mass material of several landslides indicate nearly saturated conditions of the landslide body.

2.2. Study data

The TLS measurement was conducted in October 2015, using a Riegl VZ-2000 scanner (Fig. 3a)[21].This scanner has a vertical view angle of 100° (+60°/-40°) and a full 360° horizontal view angle, with an effective measurement rate up to 400000 points per second (Table 1). Inside the forest, seven scans were performed (Fig. 1) in order to achieve a good coverage of all trees from different directions.Reflectors were placed on trees and used for the co-registration of various scans. Afterwards, the seven scans were registered using Riegl'sRiSCAN PRO software (http://www.riegl.com).The overall registration accuracy is ±7.5mm. The accuracy of orientation of individual scan is given in Table 2.Subsequently, all acquired data werefurthergeoreferenced to the coordinate system GK M28,