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Merging terrestrial laser scanning technology with photogrammetric and total station data for the determination of avalanche modeling parameters

Alexander Prokop [a,*], Peter Schön [a], Florian Singer [a], Gaëtan Pulfer [b], Mohamed Naaim [b], Emmanuel Thibert [b], Alvaro Soruco [c]

[a] Institute of Mountain Risk Engineering, Department of Structural Engineering and Natural Hazards, University of Natural Resources and Applied Life Sciences, Vienna, Austria
[b] IRSTEA, UR ETGR, Erosion Torrentielle Neige et Avalanche, Grenoble, France
[c] Instituto de Geologia y del Medio Ambiante (IGEMA), Universidad Mayor de San Andres, La Paz, Bolivia

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ABSTRACT

Dynamic avalanche modeling requires as input the volumes and areas of the snow released, and consequently the fracture heights. Determining these parameters requires high-resolution spatial snow surface data from before and after an avalanche. In snow and avalanche research, terrestrial laser scanners are used increasingly to efficiently and accurately map snow surfaces and depths over an area of several km^2. In practice however, several problems may occur, which must be recognized and accounted for during post-processing and interpretation. Thus, we combine terrestrial laser scanning with photogrammetry, total station measurements and field snow observations to document and accurately survey an artificially triggered avalanche at the Col du Lautaret test site (2058 m) in the French Alps. The ability of TLS to determine avalanche modeling input parameters efficiently and accurately is shown, and we demonstrate how, merging TLS with the other methods facilitates and improves data post-processing and interpretation. Finally, we present for this avalanche the data required for the parameterization and validation of dynamic avalanche models.

1. Introduction

In dynamic avalanche modeling, the areas and volumes of snow released in the starting zone, and consequently the fracture heights are key input parameters (Eglit and Demidov, 2005; Gruber and Bartelt, 2007; Sovilla and Bartelt, 2002; Sovilla et al., 2007). The fracture heights can in some cases be measured in the field, but in others the avalanche release zone may be difficult or impossible to access, or continued avalanche hazard may prevent a safe investigation of the avalanche crown. Even more complex is determining the total volume of snow released in an avalanche. This task requires the application of remote sensing to obtain high-resolution spatial snow surface data from before and after an avalanche.

In snow and avalanche research, terrestrial laser scanning (TLS) is used increasingly to accurately map the snow depth distribution. Laser scanners emit a pulse of light in the near-infrared spectrum. The pulse hits the terrain or snow surface and is reflected. A photodiode in the scanner detects the returning pulse, and determines the distance to the surveyed point from the travel time of the pulse. The data from the reflected pulses are saved in a point cloud in the scanner's internal coordinate system. The point cloud can be registered (geo-referenced) in a global coordinate system. This transformation into a global coordinate system is described by three translational and three rotational parameters and also requires the position of the laser scanner in the global coordinate system (Prokop, 2008). Prokop (2008), Prokop et al. (2008) and Grünewald et al. (2010) report mean deviations between TLS data and reference tachymetry measurements of 0.04–0.1 m for target distances reaching 500 m, depending on the conditions and the laser scanner.

Laser scanners can survey an avalanche path or snow area of several km^2 in a short time (<2 h) for typical point cloud density of about 10 points/m^2 and are very efficient in operation. Therefore, they are used at several avalanche test sites to survey avalanche events either terrestrial, or airborne based (e.g. Bartelt et al., 2012; Maggioni et al., 2013; Prokop, 2009; Sailer et al., 2008). Laser scanners are efficient in use and accurate in theory, but several problems exist in practice. Meteorological and snow conditions may not be ideal. Fog and snowfall can limit or preclude surveys, or the snow surface properties can change during the survey. For example, warming air temperatures may increase the liquid water content of the snow surface, resulting in a reduction of received laser signals (Prokop, 2008). The scan pulse may also be reflected on certain terrain features, such as rocks, causing a scan shadow with no data behind the feature.

* Corresponding author.

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Time–pressure due to operational time constraints may also cause less-than ideal circumstances and surveying setups. For example, the scanning time may be shorter than desired, either due to short available time windows between the scanner setup and a scheduled artificial avalanche release, or because of a short window with suitable weather conditions. Such situations may require faster scan times and lower resolutions. Furthermore, when a tripod is used, external influences may cause slight movements of the scanner and errors in the registration process (Prokop, 2008). This problem of a scanner movement is more likely to occur if the ground cover is soil, as opposed to solid rock or has a concrete cover. If any of these situations occur, they must be recognized and then accounted for in the post-processing procedure. During data post-processing and interpretation, further errors can be related to the registration of the scans and the exact delineation of avalanches zones. In order to reduce these uncertainties, additional data to control and verify the TLS data can be applied. In our case we used topographic data of the deposit area, and the position of the front of the avalanche was recorded at several time steps with time-lapse photogrammetry (described in detail by Thibert et al., 2013). From those data, we could reconstruct the lateral boundaries of the avalanche, and compare them to the boundary derived from the TLS data. In addition, detailed images of the starting zones helped to identify scan shadows, thereby facilitating the delineation of the exact starting zone boundaries. Field observations provided information about the weather and the snow conditions. The measured snow densities assisted in verifying the volume changes calculated from the TLS data.

With the addition of these methods, which are also sometimes applied at other avalanche test sites (e.g. Bartelt et al., 2012; Maggioni et al., 2013; Prokop, 2009; Sailer et al., 2008), we could improve our TLS results over our results presented in the ISSW 2013 Proceedings. The 2013 results we had were obtained solely through the interpretation of TLS data (Prokop et al., 2013). In this paper, we provide the expanded and improved results, based on our multiple technique survey, and show the deviations to the initial TLS-only results. These revised results can be used confidently as input and for validation of dynamic avalanche modeling of the Col du Lautaret avalanche.

From TLS measurements we additionally extract data along the avalanche path to quantify the volume of eroded material depending on the slope angle. This is done to provide input data for the validation of dynamic avalanche model or to assess rheological parameters of the avalanche using e.g. the approach of Naaim et al. (2004).

2. Study site

Since several decades, avalanche test sites are used for avalanche dynamics studies. Our research took place at the Col du Lautaret test site, located next to a 2058 m high pass road in the Hautes-Alpes department in the French Alps. The site is owned and operated by the ETGR (Erosion Torrentielle, Neige et Avalanches) research unit of IRSTEA (Institut national de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture, previously Cemagref; IRSTEA, 2013). The site is operational since 1972 and comprises a total of eight avalanche paths. Two of these paths are currently equipped with instruments for avalanche research. These measurements are avalanche impact pressures, velocities and flow heights (Barbolini and Issler, 2006; Naaim et al., 2001; Pulfer et al., 2013; Thibert et al., 2008, 2013). Information about the snow conditions is obtained performing manual snow-pits close to the release zone. This includes snow density, temperature, hardness as well as grain types and characteristic size.

The data, which we present, are from an avalanche released on 13 February 2013 on path n°2, located on the south-east face of the Crête de Chaillol (2600 m). The avalanche path has a length of 800 m, a vertical drop of 450 m, and an average inclination of 34° (Barbolini and Issler, 2006). The avalanches on this path are artificially released with a Gazex remote device (Interfab, 2013).

3. Terrestrial laser scanning: data acquisition and processing

In order to detect changes in the snow surface resulting from the avalanche, we took two successive scans of the avalanche path, one prior and one after the avalanche, using a Riegl LPM-321 laser scanner (Fig. 1, http://www.riegl.com/). Due to the limited available time of 2 h between the setup of the scanner and the release time, we had to setup the scanner rather quickly, to allow for sufficient time of 1.5 h for a scan of the slope prior to the scheduled avalanche release. The scanner was mounted on a tripod, with the legs placed on rocks and soil beneath the snow cover. Such a setup is typical in practice, wherever a fixed scan position with stone or concrete groundcover is absent.

The horizontal resolutions of the point clouds were lowest 0.5 m (scan 1, prior to the avalanche release) and 0.3 m (scan 2, after the avalanche release) in the start zone of the avalanche. The limited availability between the setup of the scanner and the release required a faster scan time (1.5 h) and a lower resolution for scan 1. Scan 2 took approximately 2.5 h, allowing for a higher resolution. The scan area covered approximately 48,000 m^2.

In order to compare the two scans, we had to align the scans to each other. For the alignment, we applied an iterative closest point (ICP) algorithm available in RiPROFILE, called "multi-station adjustment" (Besl and McKay, 1992). This algorithm works best with plane surfaces (Prokop and Panholzer, 2009). During the multi-station adjustment, the scan positions were modified iteratively to find a best fit, using tie-points and plane patches placed on both snow surfaces. These plane patches must be planar, and in our scan areas, the snow surface provided 24 suited plane surfaces. The standard deviation between the tie-points and plane surfaces of the two scans is ± 0.0253 m. Following the relative alignment of the scans, we registered the scans in a global coordinate system (French national grid Lambert, zone III), using surveyed targets positioned on the slope and multi-station adjustment with a referenced (snow-free) digital elevation model (DEM) of the area. For filtering non-ground points we used wedge filtering (Panholzer and Prokop, 2013). The overall standard deviation between the scans and the absolute coordinate system of the reference DEM is ± 0.34 m.

The heterogeneously distributed point clouds of the two scans had to be converted into raster surfaces, applying natural neighbor interpolation (Prokop and Panholzer, 2009) in ArcGIS. This resulted in two digital snow surface models (DSM) from before and after the avalanche release. We delineated the starting, track and deposit zones in ArcGIS and GRASS GIS 7 (Figs. 4 and 5). We defined that the area where the snow failed as the starting zone, delimited by a fracture line, and the zone where the avalanche decelerated and debris deposition was observed as deposition zone (Figs. 4 and 5). We refer to the zone of avalanche movement and snow entrainment between the starting and deposit zones as avalanche track (Fig. 5). We delineated areas of deposition and erosion/entrainment based on net changes in snow heights between the two scans. Hence, an increase of the snow height of 0.2 m can have resulted from 0.2 m of deposition, but also 0.3 m of erosion followed by 0.5 m of deposition. Therefore, the scans show solely the net changes from before and after the avalanche release, but give no information about the processes involved. The resulting net changes in volumes we calculated in ArcGIS with the Cut/Fill tool. During the post-processing it became evident that the scanner had moved slightly during one of the scans. This was caused by placing the tripod on insufficiently firm ground, and the resulting slight tilt we had to account for with extensive post-processing and multi-station adjustments. Since the study presented in the ISSW Proceedings (Prokop et al., 2013), we increased the quality of the relative multi-station