Multi-temporal long-range laser scanning for spatial deformation monitoring of alpine slopes

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Abstract

In this study we apply an approach for spatial deformation monitoring to multi-temporal long-range terrestrial laser scanning (TLS) data of alpine terrain. The approach used for distance measurement is fully 3D and robust against surface roughness and low point densities. In order to be able to distinguish between real changes and measurement uncertainties, a level of detection (LOD) is computed. The LOD is based on a confidence interval considering spatially variable positional uncertainties, local surface roughness and registration errors. Distance calculation and LOD assessment are applied to a multi-temporal TLS data set of a high alpine deep seated rockslide in the Eastern Alps (Austria). The approach is used i) to verify the data quality and ii) to analyse geomorphological processes like rockfall and debris slides. These methods and the results obtained form the basis for further geological and geomorphological analyses and interpretations.

1 Introduction

Terrestrial laser scanning (TLS) is an emerging method for spatial deformation monitoring of constructions and is established for shorter ranges. Deformation monitoring of large alpine rock slopes is more challenging because of larger measurement distances and rough terrain. Positional uncertainties of the point measurements are increasing with range due to the widening and elongation of the laser footprint. High local surface roughness (fractured rock mass, vegetation), varying point densities and scan shadows due to a limited choice of scan positions are causing additional spatially variable uncertainties. These uncertainties can be reduced by an appropriate distance measurement method. Vertical and overhanging structures in TLS data require a 3D distance measurement. 2.5D methods which measure the distance between point clouds and meshes have the drawback that missing data from scan shadows and high surface roughness are causing significant uncertainties. Methods which measure the shortest distance between two point clouds of different epochs can deal with data gaps but are not robust against surface roughness and cause uncertainties especially in regions with low point densities.

In order to be able to differentiate between real changes and data noise, a minimum distance threshold (level of detection, LOD) must be defined. This threshold is very often derived by using the error statistics describing on how well target constraints are matched (e.g. HERITAGE & HETHERINGTON 2007). Especially at larger ranges this assessment of the error budget has been shown to be an incompetent measure (FAN et al. 2015). Other approaches define the LOD by measuring deviations in areas assumed as stable (e.g.

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KROMER et al. 2015). The TLS error budget is not uniformly distributed in space and additionally varies according to range, incidence angle, surface roughness and registration error. Spatially variable uncertainties in the distance measurement related to the surface roughness have been considered by LAGUE et al. (2013). FEY & WICHMANN (2016) extended this approach and also consider spatially variable uncertainties caused by laser footprint elongation due to large ranges and low incidence angles.

In this study we apply a geomorphological change detection approach developed by FEY & WICHMANN (2016) to analyse the activity of a deep seated rock slide.

2 Study site and data acquisition

The Bliggspitze rockslide is located in the upper Kaunertal valley, Eastern Alps, Austria. The rockslide became active in the summer of 2007 and has been monitored annually by TLS since 2012. The rockslide is accompanied by secondary processes like debris slides, debris flows and rockfall. The rockslide area and adjacent slopes show steep and rugged rock faces, highly fragmented bedrock, talus slopes, and partially glaciated areas.

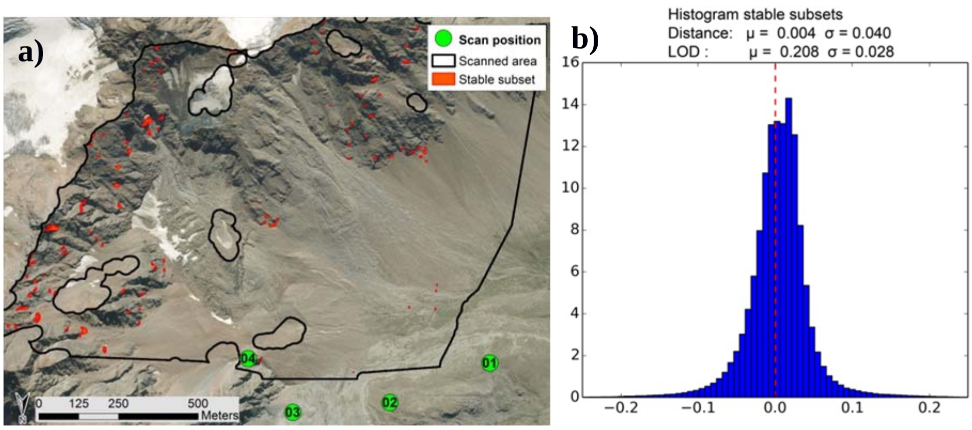

Figure 1: a) Scan setup and stable subsets used to assess the error budget b) histogram of the point cloud distance measurements in all stable subsets.

Here we present a change detection analysis between the TLS datasets acquired in August 2015 and August 2016 with a Riegl VZ 4000 terrestrial laser scanner. The scanner has a beam divergence of 0.15 mrad and operates with a laser wavelength in the near infrared. The rockslide has been scanned from four scan positions located at the counter slope. An angular resolution of 0.0075° was chosen for all scans. The distances between the scan positions and the slope vary from 80 m to 1600 m. The surveyed area has a width of 2 km and the altitudes range from 2600 m to 3350 m (Figure 1a).

3 Methods

3.1 Registration and pre-processing

The registration is done by use of an iterative closest point algorithm. In this study we used an airborne laser scanning point cloud from 2012 as reference point cloud with the aim to define the global coordinate system (ETRS 89 UTM 32N). The single scan positions from 2015 were matched onto stable areas of the reference point cloud. The entire point cloud from 2015 was then used as reference for the registration of the point cloud from 2016.

After the registration the four scan positions of each epoch were merged and then thinned out to a point density of at most one point in a cube of 10 cm. The merged and thinned point clouds are still made up of more than 80 million points.

3.2 Distance calculation

The methods for robust distance measurement and LOD calculation have been implemented in the software package Laserdata LIS (WICHMANN 2016), a commercial add-on to the FOSS GIS SAGA (System for Automated Geoscientific Analyses, CONRAD et al. 2015).

For distance calculation the surface of both point clouds is approximated by two planes fitted into the local point neighbourhood. In a preliminary step for each point in the point cloud the normal vector is calculated by a robust plane fitting within a k-nearest neighbour search neighbourhood. Along the normal direction of point A in point cloud A the nearest the neighbour in point cloud B is searched within a defined normal tolerance and a maximum distance. In a next step planes are fitted into the nearest neighbours of point A and point B by least-squares fitting. The radius used for least squares plane fitting can be adapted in dependence on point density, scale and surface roughness. In a further step point A is projected to its fitted plane and the distance to the fitted plane of point B is measured along the normal of point A. A more detailed description is given by FEY & WICHMANN (2016).

In this study two iterations with different parameter settings (normal vector tolerance, search radii for the normal and least-squares plane fitting, maximum search distance) are applied to the TLS data set of the rockslide. The first iteration is done to verify the data quality and to approximate the registration error. The second iteration is done with the aim to analyse geomorphological activity.

3.4 Handling of uncertainties in change detection analyses

For the definition of a LOD, which is necessary to distinguish between real change and data noise, the estimation of the error budget is essential. FEY & WICHMANN (2016) extended the LOD approach of LAGUE et al. (2013) and additionally consider the spatially variable positional uncertainties in the data sets besides the registration error and the local surface roughness. The positional uncertainty for each laser point related to range and local incidence angle are estimated using the approach of SCHÄR et al. (2007). In scans with rough terrain and the lack of big planar objects the registration error cannot be distinguished from the positional uncertainties and the measurement uncertainties caused by surface roughness. For that reason we perform distance measurements between the point clouds from 2015 and 2016 in selected stable subsets (rockwalls, faces of big boulders with different slope angles and orientation) well distributed over the study area (**Figure** 1 a). The standard deviation of the distance measurements is then used as a substitute for the registration error. The surface roughness is estimated from the fitting variance of the least-squares fitted planes in the distance calculation process. The LOD is calculated with a confidence interval of 95%.

4 Results

The mean standard deviation of the distance measurements between the point cloud from 2015 and 2016 in stable areas is 0.04 m. The distribution shows a very slight positive bias (Figure 1 b). The mean standard deviation is used in the calculation of the LOD, which is shown in Figure 2. A detailed discussion about the dependence of the LOD on range, incidence angle, surface roughness and point density is provided by FEY & WICHMANN (2016). The lowest LOD values (0.11 m) are close to scan position 04 and can be explained with low positional uncertainties due to short ranges. The highest LOD values (0.6 m) are located in areas farthest from the scan positions with very low point densities. At the rock walls facing northeast the LOD ranges from 0.18 m (high slope angles, perpendicular to the scanner) to 0.28 m (low slope angles). At the highly fragmented and thus very rough northwest facing slopes the LOD ranges in dependence on incidence angle and point density between 0.24 m and 0.32 m.

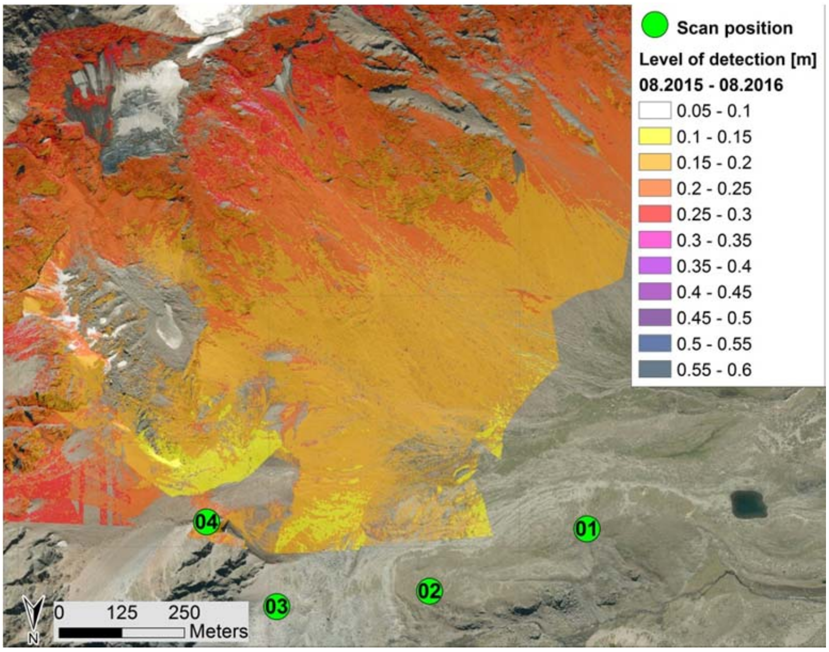

Figure 2: Spatial variability of the LOD.

In case the encountered distance is larger than the LOD the measurement is classified as real change. Figure 3 shows all areas with automatically detected changes. Positive distances (shown in blue) indicate mass accumulation and negative distance measurements (shown in yellow to red) correspond to mass loss. The patterns produced by the distance measurements reveal geomorphological processes related to failures, erosion and accumulation. At the northeast face rockfall scarps with an erosion of more than -15 m (location (a) Figure 3) and -5.7 m (location (b) Figure 3) can be identified. The accumulations (+5 m) beneath these scarps (labelled as location (c) in Figure 3) can be attributed to rockfall and debris accumulations. The distance measurements also show an uplift of the lower part of the glacier (about +5 m) at location (d) which results from the complex deformation behaviour of the rockslide. At the northwest facing talus slope (location (e)) the formation of a debris slide with erosion (-6.5 m) and accumulation areas (5m) are visible. Some smaller debris flows in channels (location f-g) with mass relocations can further be identified at the north west face.

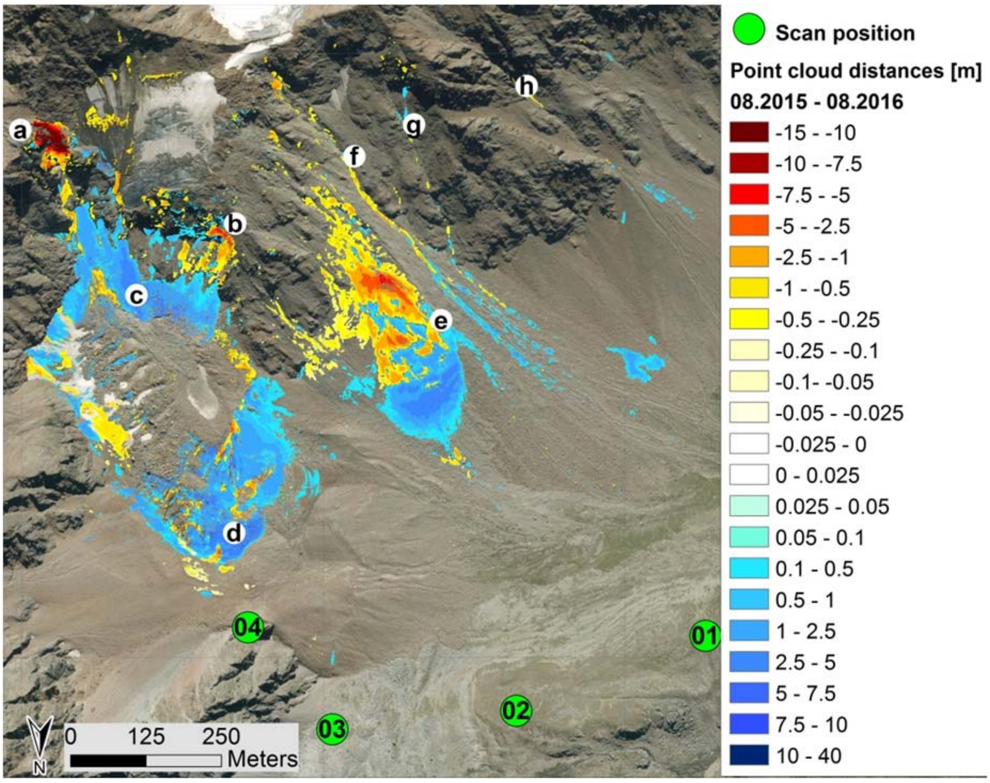

Figure 3: Point cloud distance measurements in areas automatically detected as changed. The characters a-h are described in the text.

5 Discussion

The methods for distance calculation and LOD assessment applied in this study are the first steps for rockslide monitoring based on TLS. The first iteration of distance calculation is important to verify the quality of the registration process at stable subareas. The interpretation of the distance measurement statistics of these areas can help to identify whether a scan position or the entire scan is strongly misaligned. In the second iteration the distance measurements together with the LOD calculation are used for geomorphological process interpretation. The method is able identify erosion and accumulation areas of rockfall, debris slides and debris flows, and can be used as a basis for 3D volume quantifications. Sliding processes can only be identified by regular patterns of mass losses and mass accumulations. In the case study Bliggspitze these displacements are below the LOD and are thus not shown in the change detection maps. Other methods like image correlation (FEY et al. 2015) or IPC derivations (TEZA et al. 2007) are more appropriate to analyse displacements by sliding.

The LOD considers the spatial variability of positional uncertainties caused by low incidence angles, long ranges and local surface roughness. The consideration of the spatial variability of the registration error would further enhance the LOD assessment and is topic of further research.

References

CONRAD O, BECHTEL B, BOCK M, DIETRICH H, FISCHER E, GERLITZ L, WEHBERG J, WICHMANN V, BÖHNER J. 2015: System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. Geoscientific Model Development 8: 1991–2007.

FAN L, SMETHURST JA, ATKINSON PM, POWRIE W. 2015. Error in target-based georeferencing and registration in terrestrial laser scanning. Computers & Geosciences 83: 54–64.

FEY, C.; RUTZINGER, M.; WICHMANN, V.; PRAGER, C.; BREMER, M.; ZANGERL, C. 2015: Deriving 3D displacement vectors from multi-temporal airborne laser scanning data for landslide activity analyses. GIScience & Remote Sensing 52/4, S. 437 - 461.

FEY C., WICHMANN V. 2016. Long-range terrestrial laser scanning for geomorphological change detection in alpine terrain – handling uncertainties. In: Earth Surf. Process. Landforms. DOI: 10.1002/esp.4022

HERITAGE G, HETHERINGTON D. 2007. Towards a protocol for laser scanning in fluvial geomorphology. Earth Surf. Process. Landforms 32(1): 66–74.

KROMER RA, HUTCHINSON DJ, LATO MJ, GAUTHIER D, EDWARDS T. 2015. Identifying rock slope failure precursors using LiDAR for transportation corridor hazard management. Engineering Geology 195: 93–103.

LAGUE D, BRODU N, LEROUX J. 2013. Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (N-Z). ISPRS Journal of Photogrammetry and Remote Sensing 82: 10–26.

SCHÄR P, SKALOUD J, LANDTWIG S, LEGART K. 2007. Accuracy estimation for laser point cloud including scanning geometry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences(37 (Part B)): 851–856.

TEZA G, GALGARO A, ZALTRON N, GENEVOIS R. 2007. Terrestrial laser scanner to detect landslide displacement fields: A new approach. International Journal of Remote Sensing **28**(16): 3425–3446.

WICHMANN V. 2016. Laserdata LIS Command Reference, Version 3.0.