Geomonitoring with TLS

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Quantifying and Reducing the Uncertainty of 3D Displacement Estimates from Terrestrial Laser Scanner Point Clouds – A Case Study in Alpine Geomonitoring

Terrestrial laser scanning (TLS) can offer an effective solution to geomonitoring problems by providing highresolution point clouds, which serve as a basis for estimating dense 3D displacements. The uncertainty of such estimates, as well as the means of reducing it remain largely unexplored. We present a case study to evaluate the accuracy of TLS-based deformation estimates from an alpine monitoring campaign consisting of 6 scanning epochs between 2019 and 2022. The point clouds acquired with a Riegl VZ-4000 scanner were processed using the Feature to Feature Supervoxel-based Spatial Smoothing (F2S3) algorithm to estimate the 3D displacement vectors. We compared these vectors to sparsely distributed ground truth measurements, acquired using Global Navigation Satellite System (GNSS) stations. The results showed that, if adequately spatially averaged over large areas, the 3D vectors can be estimated with an accuracy of a few centimeters despite the long distances of up to 4 km. This corresponds to an accuracy of a few centimeters for the displacement magnitude, and a few degrees for the direction (if the magnitude is large enough for a meaningful estimate of the direction). Herein, we additionally explore several strategies to reduce the uncertainty, where temporal averaging of multiple consecutive scans from a single epoch proved to be the most promising one, while vegetation filtering and a careful selection of the registration approach indicated limitations that require further investigations.

Keywords: Geomonitoring, Terrestrial laser scanning, Point clouds, 3D displacement

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D. Czerwonka-Schröder, F. Schulte, W. Albert, K. Hosseini, R. Tabernig, Y. Yang, B. Höfle, Ch. Holst, K. Zimmermann

AImon5.0 - Real-time monitoring of gravitational mass movements for critical infrastructure risk management with AI-assisted 3D metrology

The Earth's surface is constantly changing. Climate change is altering environmental conditions - for example, more intense and prolonged precipitation is causing more frequent landslides or rockfalls. Such events do not only affect the local population but also critical infrastructure. A key tool in integrated risk management is the availability of 4D geo-information. The information is collected through continuous monitoring in near real time. The current state of the art is fixed and autonomous permanent laser scanner (PLS) systems. PLS provide huge amounts of data. In order to make PLS and 4D analysis methods available for operational use and to limit the big 4D data to the relevant information, a new interface between the information needs of the application and the 4D acquisition and analysis is required. For the first time, this will make it possible to use state-of-the-art PLS in risk monitoring and, with the help of artificial intelligence methods, to find and evaluate specific relevant events in the huge amounts of data, to follow them in continuous monitoring and to automatically identify new events. AImon5.0 is an interdisciplinary collaboration project. The expertise of all partners will be combined to close the gap between research and application. This paper presents an advanced method using permanent laser scanners. We show how we address scientific questions from an engineering geodetic point of view, as well as in the efficient extraction of essential information from large datasets. We present a conceptual approach that clearly illustrates the interfaces from data acquisition to information.

Keywords: Permanent laser scanning, Geomonitoring, Multitemporal 3D point cloud analysis, Hierarchical analysis

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Using point cloud registration to mitigate systematic errors in permanent laser scanning-based landslide monitoring

Permanent laser scanning technology has been utilized for continuous monitoring of natural hazards over the past decade, owing to its ability to capture high spatio-temporal resolution point cloud time series, termed 4D point clouds (3D space + time). These 4D point clouds from PLS enable the detection of intricate surface changes and deeper insights into Earth's surface processes. However, due to the potential instability of the installation platform and environmental variations, significant systematic errors may occur in the point cloud data across different epochs. In this study, we assume that the dominant systematic shifts cause an approximate rigid-body movement of the entire point cloud surface based on the investigation and analysis of continuous total station measurements. By applying rigid registration to the stable areas, we can optimally align these point clouds and thus mitigate the deviations between scanned surfaces. These deviations can reflect the comprehensive impacts of systematic errors during monitoring, such as changes in scanner position and orientation and refraction effects. Preliminary analyses of systematic errors in PLS are conducted on a dataset from a PLS system installed in Vals Valley (Tyrol, Austria) for monitoring a landslide. The total station measurements and the transformation parameters derived from targetless registration exhibit significant daily periodic patterns. Through robust registration, these centimeter-level systematic errors can be mitigated to the millimeter level without using artificial targets or additional sensors.

Keywords: Permanent laser scanning, Total station, Uncertainty reduction, Atmospheric refraction, Targetless registration

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Contour line extraction and feature tracking for real-time 4D landslide monitoring based on point clouds: Proof of concept with lab experiments

Landslides are a pervasive natural hazard with significant societal and environmental impacts. Several methods for monitoring landslides exist, including comparing point clouds from two different epochs directly using the M3C2 algorithm. The main challenge for existing methods is the size of point cloud data sets, which are not computationally efficient enough to process in real time. In this research, we develop an algorithm for real-time landslide monitoring by using a mixture of contour lines to cluster deformed areas and feature tracking to detect small deformations in the pre-clustered areas. The first step involves roughly identifying the deformed area because applying feature extraction and matching on the entire data set is computationally intensive and time-consuming. Detecting these small deformations in the deformed areas, which happens in the feature tracking, could be helpful in predicting the next stage of a landslide and issuing necessary warnings. The method was tested on a controlled laboratory dataset, providing an ideal environment to validate the method's precision, achieving sub-millimeter accuracy under controlled conditions. The results showed that the method is well-suited for real-time monitoring, accurately detecting the deformation's magnitude and direction.

Keywords: Deformation analysis, Terrain deformation, Feature detection, Hillshade, Permanent laser scanning