Advanced point cloud analysis strategies for deformation analysis

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O. Geißendörfer, Ch. Holst

Spatio-temporal mode description in LiDAR point clouds

Analyzing objects concerning their static and dynamic change is mostly performed with IMU (Inertial Measurement Units) or GNSS (Global Navigation Satellite System) sensors fixed to a physically defined surface. We can use a total station to record additional data or support other sensors by referencing them to a homogeneous coordinate frame. LiDAR (Light Detection and Ranging) enables simultaneous, contactless, spatially connected, and time-referenced observations recording an object.
All sensors share the ability to detect equivalent signal properties concerning different signal-to-noise ratios. Since object deformation is not limited to a fixed position, we must continuously model or interpret the dynamic movement within our processing to get a spatio-temporal understanding. Therefore, LiDAR offers advanced options for understanding the spatio-temporal behavior of an object with a frequency analysis executed in the or time domain.
In our work, point clouds are processed in a state-of-the-art time series analysis of discretized locations in the frequency domain. Furthermore, fusing point cloud observations in a time domain approach offers a unique opportunity to analyze the spatio-temporal behavior of objects. This observation-level fusion reduces the number of required processing steps. The resulting parameter model leads to simplification of present periodic signals, yet retaining spatial and temporal consistency and streamlining subsequent interpretation.

Keywords: MEMS-LiDAR, Frequency analysis, Mode analysis

R. Tabernig, W. Albert, H. Weiser, B. Höfle

A hierarchical approach for near real-time 3D surface change analysis of permanent laser scanning point clouds

Modern permanently installed laser scanning systems (PLS) allow capturing point clouds in short intervals (e.g., sub-hourly), bringing us closer to the early detection of small surface changes that may precede larger events.

Predicting potential hazards necessitates near real-time surface change computation. This requires reliable and efficient methods that can be operated directly on laser scanners in the future. We propose a method that combines low-resolution (meters) change detection with high-resolution (centimeters) change analysis. First, utilizing the Mahalanobis distance, a change detection approach identifies significant intravoxel changes, filtering out temporary changes (e.g., tree movements due to wind) to retain only persistent, relevant changes (e.g., rock movements). Second, sub-point clouds of areas exhibiting significant change are extracted and subjected to point cloud-based surface change analysis. Hierarchical analysis of point clouds with fine-tuned key parameters results in a data volume reduction of over 95% and a miss rate of less than 6%, both relative to a manually annotated reference point cloud. Furthermore, a computation time decrease of 97% is achieved relative to an M3C2-only run. Our approach is based on the hierarchical detection and analysis of areas exhibiting surface change. This method is particularly efficient when these areas are considerably smaller than the monitored area, allowing processing within seconds and much faster than data acquisition. A further advantage is that this methodology is implemented using the open-source Python libraries py4dgeo and VAPC, which enables straightforward integration into your own PLS monitoring workflows, allowing processing much faster than data acquisition (e.g. within seconds).

Keywords: Hierarchical analysis, Permanent laser scanning, Change detection, Change analysis

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A. Voordendag, D. Haener, A. Wieser

Plane-based deformation analysis of railway tracks using airborne laser scanning data

Early detection of changes in the ballast of railway tracks and timely maintenance are important to ensure a highly-available and affordable railway service. In this paper, we present a novel method utilizing point clouds to detect ballast problems and assess temporal changes of a track. We assume that consecutive sleepers locally approximate a plane, with deviations of the point cloud from this plane indicating ballast anomalies, and changes of the planes over time indicating deformations of the track. We demonstrate the method using airborne laser scanning data of a 430m long part of a railway track in Switzerland. The results indicate areas with ballast prob-

lems through a high percentage of anomalies (>30% in some cases). Our method provides more, and more easily interpretable, information about track conditions than conventional point cloud based deformation analysis, like M3C2. It is applicable to photogrammetric point clouds as well as point clouds from different LiDAR sensors and platforms. As such, it complements existing track inspection and monitoring approaches, and helps to improve railway infrastructure management.

Keywords: Railway tracks, Ballast, Deformation monitoring, Point clouds, ALS, M3C2

M. E. Kowalska, J. Zaczek-Peplinska

Exploring Planar Projection of Point Clouds: A Case Study with Cylindrical Objects

Terrestrial laser scanning is widely employed for assessing deformations in structures with diverse geometries, offering a quasi-continuous surface model that accurately reflects current geometric parameters. However, interpreting laser scanning results remains challenging, limiting its adoption as a reliable solution for construction measurements. Point clouds derived from terrestrial laser scanning are often considered supplementary due to difficulties in visualization and precise analysis. In practice and literature, deformation analysis of complex geometric objects typically involves vertical and horizontal cross-sections or color-coded three-dimensional models to illustrate specific deformations. Nevertheless, these methods have inherent limitations, prompting research into projecting point clouds onto a plane for geodetic monitoring. While the mathematical concept of surface projection onto a plane is well-established, applying this to deformation analysis requires a specialized approach, including careful parameter selection and accuracy assessment. Additionally, methods of point cloud filtering, thinning, and classification significantly influence deformation analysis outcomes. This article proposes a solution using cylindrical objects as a case study, demonstrating the method's applicability for monitoring tunnels, vaults, collectors, and other structures.

Keywords: Terrestrial laser scanning, Planar projection, Cylindrical objects.
