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Data infrastructure for multitemporal airborne LiDAR point cloud analysis – Examples from physical geography in high mountain environments

Lorenzo Rieg [a,*], Volker Wichmann [b,c], Martin Rutzinger [a,d], Rudolf Sailer [a,b], Thomas Geist [e], Johann Stötter [a]

[a] Institute of Geography, University of Innsbruck, Austria
[b] alpS – Centre for Climate Change Adaptation Technologies, Innsbruck, Austria
[c] Laserdata GmbH, Innsbruck, Austria
[d] Institute of Interdisciplinary Mountain Research, Austrian Academy of Sciences, Austria
[e] Austrian Research Promotion Agency, FFG, Austria

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ABSTRACT

The application of multi-temporal topographic LiDAR data has become a standard for many mapping and monitoring applications in man-made and natural environments. With increasing availability of area-wide, high-resolution, multi-temporal datasets and the increasing interest in working with the original measured 3D topographic LiDAR point clouds, challenges regarding optimal data storage and management are gaining in importance. During the last decade, an unique LiDAR dataset, consisting of over 30 flight campaigns covering different areas in western Austria and northern Italy, has been acquired with the purpose to analyse surface changes in high mountain environments. The datasets from each flight campaign are stored and managed in a LiDAR specific information system (LIS, Laserdata Information System), which has a client–server architecture and a spatial relational database as a core. The system is integrated into an open source Geographical Information System, which allows a seamless integration into operational spatial data processing and analysis workflows. It enables multi-user access to 3D point cloud data and additional attributes, such as intensity, return number, global positioning system time, flight path trajectory information and fullwaveform attributes if available. In this paper we describe the available dataset, the approach to 3D point cloud storage and management and the structure of the database. The value of direct access to the stored 3D point cloud data is assessed as well as the importance of storing point cloud attributes. A further focus lies on the importance of the data management and infrastructure for the analysis of large areas and long time series of topographic LiDAR data.

1. Introduction

During the last decade, multitemporal Airborne Laser Scanning (ALS), using LiDAR (Light Detection and Ranging) technology has been widely used for change detection and monitoring purposes (Höfle & Rutzinger, 2011). Examples are the identification and quantification of surface changes due to geomorphological processes, e.g. the distribution of debris and sediment pathways caused by landslides (Bull et al., 2010), the monitoring of changes in coastlines (White & Wang, 2003) or the quantification of geomorphological processes (Joyce et al., 2009; Sailer et al., 2012). In glaciology, multitemporal ALS data has been used extensively to quantify surface changes as input for the geodetic mass balance of glaciers (Abermann, Fischer, Lambrecht, & Geist, 2010; Fischer, 2011; Joerg, Morsdorf, & Zemp, 2012), but also for further applications, like the detection of glacier outlines and crevasses (Kodde, Pfeifer, Gorte, Geist, & Höfle, 2007; Knoll & Kerschner, 2009) and the classification of glacier surface types (Fritzmann et al., 2011; Höfle, Geist, Rutzinger, & Pfeifer, 2007).

Most of the work has been based on rasterized data, but the original 3D point data is increasingly used for several applications. Feature extraction (e.g. Brenner, 2010; Dorninger & Pfeifer, 2008; Shan & Sampath, 2009) and segmentation (Filin & Pfeifer, 2006) is used for a variety of applications, e.g. forestry (Eysn, Hollaus, Schadauer, & Pfeifer, 2012; Jochem, Hollaus, Rutzinger, & Höfle, 2011; Maas, 2010; Yu et al., 2005) and for solar potential calculations (Jochem, Höfle, Wichmann, Rutzinger, & Zipf, 2012). Breakline extraction in 3D point clouds (Briese, 2004; Mandlburger & Briese, 2009) allows the detection of surface discontinuities in steeper terrain and on overhangs, which is not possible in

* Corresponding author. Address: Institute of Geography, University of Innsbruck, Innrain 52f, 6020, Innsbruck, Austria. Tel.: +43 5125075413; fax: +43 5125072895.
E-mail address: lorenzo.rieg@uibk.ac.at (L. Rieg).

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rasterized digital elevation models (DEMs). Haas, Heckmann, Wichmann, and Becht (2012) used airborne in combination with terrestrial laser scanning (TLS) data to calculate the volume of a rockfall as well as the volume, axial ratio and run-out length of single boulders.

While the high point densities of LiDAR datasets can even make basic processing tasks like grid generation difficult, the use of 3D point cloud data places even higher demands on data management and hardware. The large amount of data which have to be handled for multitemporal analysis require optimized data management concepts, especially if large study areas with high point densities are processed. While disk space usage and processing time are important factors for working with 3D point clouds, the required access time to the stored data can be of even higher importance, especially if several users are working with the same dataset. Seamless access to the data is important, since spatial queries are one of the most frequently performed tasks when working with LIDAR data, especially if available data is used for a multitude of analyses. The seamless access therefore constitutes a basic requirement of data management systems (David, Mallet, & Bretar, 2008).

The objective of this paper is the presentation of a LiDAR data processing and analysis system, which overcomes limitations that users face when working with large and multitemporal LiDAR point cloud data and conventional spatial data processing tools and Geographic Information Systems (GIS). Therefore, an overview of the state of the art on existing systems for the management of LiDAR data is given in Section 2, while, the management of LiDAR data using LIS is explained in detail in Section 3. To show how the data management sytem is used in our research, examples of using LIS are given in Section 4. The advantages and disadvantages of a database in manging LiDAR data are discussed in Sections 5 and 6 gives an outlook on expected future developments.

2. Related work

An overview of 3D spatial information systems is given in Schön, Laefer, Morrish, and Bertolotto (2009). In general, several possibilities for the management of large LiDAR point cloud data sets exist, including file-based approaches, the use of database management systems (DBMS) and hybrid approaches. File-based approaches store LiDAR points either as ASCII (American Standard Code for Information Exchange) or binary files, usually organized by flight strips, scan positions or tiles for each data acquisition campaign. Since the publication of the LAS 1.0 specification in 2003, the LAS format of the American Society for Photogrammetry and Remote Sensing (ASPRS) has emerged as a standard for LiDAR data (Graham, 2009). Using LAS, LiDAR data are stored as original 3D point cloud data, including attributes on returns and flight parameters, such as GPS-time. Additionally, many file-based management systems also provide access to the derived 2D and 2.5D raster models such as digital surface models (DSMs), digital terrain models (DTMs), and digital intensity models (DIMs) since they are requested by a majority of the user groups. File-based systems spatially segmentize the surveyed LiDAR data into manageable portions, depending on available hardware i.e. processing and delivering infrastructure specifications. An example of a file-based LiDAR data processing environment and management system is OPALS (Orientation and Processing of Airborne Laser Scanning Data). LiDAR points are spatially indexed by a kd-tree and groups of points (i.e. tiles) and are managed using an r-tree strategy in order to provide efficient data access. OPALS especially covers preprocessing tasks necessary before data delivery to end users, including tools for strip adjustment, intensity correction, DTM filtering, etc. (Mandlburger, Otepka, Karel, Wagner, & Pfeifer, 2009; Otepka, Mandlburger, & Karel, 2009). ESRI ArcGIS 10.1 provides basic access to LiDAR point clouds via LAS format in order to bring the point cloud into their native GIS environment. The point clouds are converted into TINs (Triangulated Irregular Network) or represented by grids for further processing and distribution, for example as image service with ArcSDE (ArcGIS, 2013). Some systems have their focus on making LiDAR-data available by allowing the download of point cloud datasets via a web portal. The CLICK (Center for LiDAR Information, Coordination and Knowledge, Stoker, Greenlee, Gesch, & Menig, 2006) provides data tiled by USGS Quarter Quadrangles in LAS and ASCII format. NOAA Digital Coast (NOAA, 2013) and Qcoherent's LiDAR Server (Qcoherent, 2013) allow the data to be selected by a user-defined area of interest (AOI).

In the case of spatial databases, point cloud data are imported, indexed and stored as a specially defined point cloud geometry type. Databases provide fast access to data, but data import is a time consuming task, which has to be performed if new data is added. Often, a re-organization of the data is also needed to match the internal table structure and to allow bulk inserts (i.e. to load multiple rows of data at once). In general, query and processing time strongly depends on the table size in the database, the dimension of point groups, the point density of the input data, the indexing strategy, the complexity of the SQL (Structured Query Language) query and the hardware and its configuration (Lewis, Mc Elhinney, & McCarthy, 2012). An example of a spatial database implementation managing point clouds is Oracle Spatial 11g (Oracle, 2009), using a kd-tree-like indexing on grouped neighboring points. It supports TIN data structure and 3D object models. Chen, Zhang, and Fu (2010) present a study using SQL Server 2008 for 3D point cloud storage, implementing a 2D grid indexing strategy using 5 hierarchies and testing query performances on a TLS point cloud. Finally PostgreSQL/PostGIS (PostreSQL Global development Group, 2012) has been successfully used for building LiDAR data point cloud management systems by different independent research groups (e.g. Lewis et al., 2012, Höfle, 2007). The management system presented in this paper is also built on PostgreSQL/PostGIS.

Finally, hybrid management approaches store the original point cloud as files, which are managed and indexed by a database system on top of it. A prominent example of an operational operating management and processing system is OpenTopography (Krishnan et al., 2011; Nandigam, Baru, & Crosby, 2010). This system provides management of metadata, 3D point clouds, derived gridded DEMs and TINs, format conversion and visualization tasks. The system integrates different sub-architectures using file servers, the IBM DB2 database, DEM tile servers, streaming services for Google Earth hillshade image viewing, and LiDAR point cloud storage on the San Diego Supercomputer Center (SDSC) cloud. Alternatively, DIELMO is a web-based data selection and download service for 3D LiDAR point clouds and rasterized derivatives. It provides tools for 3D point cloud viewing and profile drawing. It is a WMS-based (Web Map Service) implementation using a grid approach to build a database index relying on its own OLX-LiDAR format (LiDAR online, 2013). Within the next section, we give a detailed description of the LiDAR data management and analysis software LIS. The software can be used both for storing and accessing huge amounts of LiDAR data and provides a comprehensive suite of point cloud analysis tools for various applications.

3. A system for LiDAR data management and analysis

LiDAR data management and data analysis are performed with LIS, a commercial add-on to the free and open-source software SAGA GIS (System for Automated Geoscientific Analysis, Conrad, 2007). The development of the system started at the Institute of