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OPALS – A framework for Airborne Laser Scanning data analysis

N. Pfeifer, G. Mandlburger [*], J. Otepka, W. Karel

Vienna University of Technology, Department of Geodesy and Geoinformation, Karlsplatz 13, 1040 Vienna, Austria

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ABSTRACT

A framework for Orientation and Processing of Airborne Laser Scanning point clouds, OPALS, is presented. It is designed to provide tools for all steps starting from full waveform decomposition, sensor calibration, quality control, and terrain model derivation, to vegetation and building modeling. The design rationales are discussed. The structure of the software framework enables the automatic and simultaneous building of command line executables, Python modules, and C++ classes from a single algorithm-centric repository. It makes extensive use of (industry-) standards as well as cross-platform libraries. The framework provides data handling, logging, and error handling. Random, high-performance run-time access to the originally acquired point cloud is provided by the OPALS data manager, allowing storage of billions of 3D-points and their additional attributes. As an example geo-referencing of laser scanning strips is presented.

1. Introduction

Digital topographic data is indispensable for modeling in urban and environmental planning, forestry, geology, hydrology, cartography, and other geo-disciplines and applications, including natural hazard studies. Topographic data includes especially terrain elevation and terrain structure lines, water bodies in the form of shore and coast lines, river axes, and glacier extents, boundaries of vegetation classes and possibly class parameters as, e.g., vegetation height or single tree position, information on individual building location and extent, including the roof structure, and infrastructure lines as roads, pipelines, power lines, etc. Its comprehensive provision became possible with stereo plotting from aerial images (Kraus, 2007), with advancements regarding a full digital work flow and sensor versatility, e.g., satellite imagery. Improvements in reliable automation was not achieved before dense point clouds were generated automatically either by image matching (Baltsavias, Gruen, Eisenbeiss, Zhang, & Waser, 2008) or from laser scanning (Baltsavias, 1999; Shan & Toth, 2008). Point clouds from airborne laser scanning (ALS), also termed airborne LiDAR (light detection and ranging), have the advantages of:

- excellent height precision which can be better than ±1 dm if appropriate techniques (Filin, 2003a; Kager, 2004; Ressl, Pfeifer, & Mandlburger, 2011) are applied,
- penetrating vegetation, i.e. seeing through the gaps in the foliage of trees and recording points on the vegetation as well as on the ground below (Maltamo, 2013),
- direct recording of a 3D point from one sensor position, making it suitable for recording of power line wires (Jwa & Sohn, 2012; Ritter & Benger, 2012), small forest clearings, and forest ground, and
- not depending on surface texture for providing 3D information.

Point density and precision are dominated by flying height, and this affects the detail to be retrieved in scene modeling. Because of the ability to record different reflections from the emitted laser pulse along the line of site, multiple echoes corresponding to different reflecting surfaces – and therefore different points – can only be provided by LiDAR. In full waveform laser scanning (Wagner, Ullrich, Ducic, Melzer, & Studnicka, 2006) additional properties of the reflecting surface can be observed, e.g., the echo width, which is related to the vertical extent of the reflecting surface within the illuminated footprint. Further information on the technical aspects of the measurement are given in Shan and Toth (2008).

In order to exploit the potential of point clouds in general and point clouds from ALS in particular, conversions like vector to raster, or the omission of additional attributes (e.g., echo number, recording time) should be avoided (Axelsson, 1999; Höfle, Vetter, Pfeifer, Mandlburger, & Stötter, 2009). A typical density of ten measurements per m^2 covering a forested or city area of 100 km^2 with, on average, two echoes per shot, results in 2×10^9 points. As ALS data may contain billions of points, efficient run time access is necessary and user interaction should be kept to a minimum. The fast technological advances additionally require correspondingly fast implementation of algorithms for the automatic production of digital topographic information. These aims are followed with OPALS,

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[*] Corresponding author. Tel.: +43 1 58801 12235; fax: +43 1 58801 12299.
E-mail address: gottfried.mandlburger@geo.tuwien.ac.at (G. Mandlburger).

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a scientific software for the Orientation and Processing of Airborne Laser Scanning data.

In this article the OPALS framework and individual OPALS modules are presented. First, in Section 2, a brief overview of processing requirements and existing software packages is given. In Section 3 the question of how ALS data should be processed is posed and answered. This leads to a suggested processing methodology for laser scanning, with focus on (i) the data properties, based on the sensor technology and on (ii) the algorithms for processing the point cloud. In Section 4 the software framework and data management are presented and their design rationales are discussed. Section 5 gives an example of assembling modules with scripting to perform a complex task, namely geo-referencing and strip adjustment. Section 6 discusses and summarizes the results.

2. State of the art in ALS processing

2.1. Algorithms

Research on algorithms for the automatic processing of ALS point clouds has reached a state in which experimental comparison of algorithms are performed, especially for automatic terrain derivation (Meng, Currit, & Zhao, 2010; Sithole, 2001; Tinkham et al., 2011), building extraction (Kaartinen et al., 2005; Rutzinger, Rottensteiner, & Pfeifer, 2009), tree identification (Kaartinen & Hyyppä, 2008), and forest parameter estimation (Tuominen & Haapanen, 2011). Simultaneously technology advances, including especially full waveform airborne laser scanning (Roncat, Bergauer, & Pfeifer, 2011; Wagner et al., 2006), exploitation of the radiometric measurements of airborne laser scanning (Höfle & Pfeifer, 2007; Kaasalainen et al., 2009; Vetter, Höfle, & Rutzinger, 2009), and the advent of multiple wavelengths in topographic and bathymetric airborne laser scanning (Mandlburger, Pfennigbauer, Steinbacher, & Pfeifer, 2011).

The underlying algorithms for the applications listed above seek to reduce the complexity of the entire point cloud by extracting meaningful subsets or a set of feature points. This can be segmentation, which is the task of grouping points that are locally neighbouring and homogeneous w.r.t. a certain predicate (Hoover et al., 1996). For point clouds this requires an appropriate neighborhood definition (e.g. all points within a certain distance are considered as neighbours) and that neighbours can be retrieved efficiently. In 'seeded region growing', for example, a segment is growing from one point by investigating all of its neighbours and adding them to the segment, if they fullfil the homogeneity requirement with respect to the current point. The homogeneity criterion is specified by the application and considers geometry (x,y,z) and possibly also the values of additional attributes. A typical example is the extraction of planes, e.g. for land parcel delineation (Filin, Borka, & Doytsher, 2009).

Alternatively, classification algorithms group points based on their attributes, without the necessity to consider spatial connectedness. These attributes may be measured directly (e.g., the echo width or the backscatter strength in ALS) or derived from local models. In the latter case, the neighborhood of each point is analysed and a measure is extracted and stored as additional attribute of the point. In Alexander, Tansey, Kaduk, Holland, and Tate (2010) a decision tree is used to classify the point cloud over an urban area into the classes tree, shrub, building, road, and grass. Combinations of classification and segmentation can be performed by object based point cloud analysis (Rutzinger, Höfle, Hollaus, & Pfeifer, 2008) in which first small segments are built which are then classified, or by random fields (Niemeyer & Rottensteiner, 2012) which classify a point also considering the class membership of the neighbouring points.

These algorithms require, in summary, for each point to (i) store application specific attributes and (ii) retrieve the neighbouring points efficiently.

2.2. Implementations and software packages

With respect to software for the processing of ALS data, packages for automatic strip adjustment (Kager, 2004; TerraScan, 1999) and automatic terrain generation (Pfeifer, Stadler, & Briese, 2001; TerraScan, 1999; Tinkham et al., 2011) are available. Automatic building reconstruction is often provided as service, but also software is available (e.g., Trimble SketchUp[1]). In either case a notable portion of manual editing is necessary for correct modeling. For forestry applications, software is often close to the academic sector (e.g., TreeVis (Univ. of Freiburg), Fusion[2] (Univ. of Washington)).

Existing software for processing of airborne laser scanning data can be categorized into, (i) vendor software, (ii) academic and or free/open source software, and (iii) commercial software which targets production lines. In the following we give a few examples, without the intention to mention all available software.

In the first category mainly software for direct geo-referencing and geometric system calibration can be found (Riegl: RiProcess, Optech: Friess (2006)). These packages are often sold with a laser scanner. Some packages go as far as terrain extraction (Realm from TopScan/Optech). Software of the second group contains open source projects for terrain extraction (e.g., ALPS,[3] Evans & Hudak, 2007; Streutker & Glenn, 2006; Tinkham et al., 2011), data handling for point clouds and performing simple manipulations (e.g., LISA (Höfle, Rutzinger, Geist, & Stötter, 2006), LiDARFormat,[4] David, Mallet, & Bretar (2008), LAS tools[5] (Isenburg, Liu, Shewchuk, & Snoeyink, 2006), pylas[6]), and viewers (e.g., FugroViewer[7]). Finally, examples for production software include TerraScan,[8] SCOP++,[9] MARS,[10] Laserdata LiS[11] or Tiltan (Petrie, 2011).

The vendor-software produces geo-referenced point clouds but does not support applications. Free software is often limited to specific tasks, whereas the commercial products aim at having the entire work flow within one software. Thus, interfacing between products becomes an issue. On the one hand, the burden originates in understanding an output data model and converting it to a required input for another processing program, and on the other hand, interfacing may not be foreseen at all. It shall be noted that the LAS format specification (ASPRS, 2013) for LiDAR point clouds has reduced the interfacing problem. This holds especially for LAS 1.4 allowing the storage of additional, user defined point attributes in a well defined way via extra byte variable length records.

A special requirement for processing airborne laser scanning point clouds is the handling of a large data volume under consideration of the irregular distribution of the points. Some of the packages solve this by rasterizing the data in an early step and proceed by processing images. Disadvantages of this approach will be detailed below. ALS processing software is typically not modular, thus individual work flows tailored for specific applications, as often found in an academic setting, cannot be assembled easily. In summary, no modular software for handling the large data volume

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[1] http://www.sketchup.com.

[2] http://forsys.cfr.washington.edu/fusion/fusionlatest.html.

[3] http://ngom.usgs.gov/dsp/tech/alps.

[4] http://code.google.com/p/lidarformat.

[5] http://www.lastools.com.

[6] http://www.perrygeo.net.

[7] http://www.fugroviewer.com.

[8] http://www.terrasolid.fi.

[9] http://www.trimble.com.

[10] http://www.rockwave.com.

[11] http://www.laserdata.at/products/index.jsp.