OPALS: A Flexible and Efficient Point Cloud Processing Software for Forest Application

J. Otepka[1], M. Hollaus[1], G. Mandlburger[1], L. Gokl[1], W. Karel[1], B. Wöhrer[1], N. Pfeifer[1]

[1]Department of Geodesy and Geoinformation, TU Wien, Wiedner Hauptstraße 8, 1040 Vienna, Austria
Email: {johannes.otepka;markus.hollaus;gottfried.mandlburger;lukas.gokl;wilfried.karel;bruno.woehrer;norbert,pfeifer}@geo.tuwien.ac.at

1. Introduction

OPALS[1] (Orientation and Processing of Airborne Laser Scanning data) is a modular and efficient point cloud processing software (Pfeifer et al., 2015) developed at TU Wien, Department of Geodesy and Geoinformation. Although the development is mainly focussed on Airborne Laser Scanning (ALS) data, OPALS is well capable of handling huge point clouds from arbitrary sensors, like static and kinematic laser scanners, single photo LiDAR (SPL), range cameras, and photogrammetric point clouds computed by dense image matching (DIM), etc.

The strong scientific background of the software is emphasised by detailed documentation of the used algorithms and concepts, with many algorithms published additionally in scientific journals. Profound processing algorithms are, however, only one pillar of OPALS. Due to the rapid technological advances and miniaturisation, modern sensors achieve enormous measurement rates (> 1 Mhz) and point densities (>200 points/m^2) resulting in huge data sets with billions of points. Hence, efficient processing strategies are an absolute necessity for a mature and operational point cloud processing software. For this reason, OPALS makes extensive use of today's multi-core processors. Based on its modular structure, it is further possible to distribute processing tasks from multiple independent computers up to large high-performance computing facilities.

OPALS consists of a range of small and well-defined modules for specific tasks. Each module can be accessed via command line, Python and C++ in a unified manner. Comprehensive workflows such as quality assessment are predefined in OPALS as Python scripts. Nevertheless, the modular and flexible structure also allows for establishing individual workflows in the preferred scripting/programming environment. Thereby, users can have full access to the individual point attributes as well as to a set of spatial queries based on generic neighbourhood definitions (Otepka et al., 2021).

From an application point of view, OPALS covers a wide range of typical processing tasks for vegetation mapping. In this contribution, we demonstrate the versatility of OPALS with three case studies covering different applications, sensors, and scales from single tree modelling using TLS to country-wide, ALS-based biomass estimation. Additionally, georeferencing and strip adjustment of UAV-borne laser scanning (ULS) data is demonstrated as first showcase since it is a prerequisite for most LiDAR processing tasks. Proper georeferencing and scan data alignment is of special importance whenever the application requires fusion of data from multiple flight strips (ALS/ULS) or scan stations (TLS) (e.g., stem diameter estimation) to unlock the full potential of the measured data.

2. Case studies

2.1. Strip Adjustment of ULS data

Depending on accuracy requirements and data quality, fine georeferencing for static LS and strip adjustment for kinematic LS can get necessary. This goes beyond the direct georeferencing provided by inertial and global satellite navigation sensors and/or the use of markers or other tie elements in TLS point clouds. It may include refining the calibration of the entire system. To decide where an improved georeferencing is necessary, typically a quality control based on differences on smooth areas between overlapping strips or TLS scan positions is performed. Statistical measures and visualisations of the differences allow assessing, if georeferencing improvements are necessary or not. In case improvement of sensor orientation is needed, opalsICP and opalsStripAdjust are the two modules for fine georeferencing of static and kinematic data sets. Special emphasis is also laid on precise orientation of

[1] https://opals.geo.tuwien.ac.at

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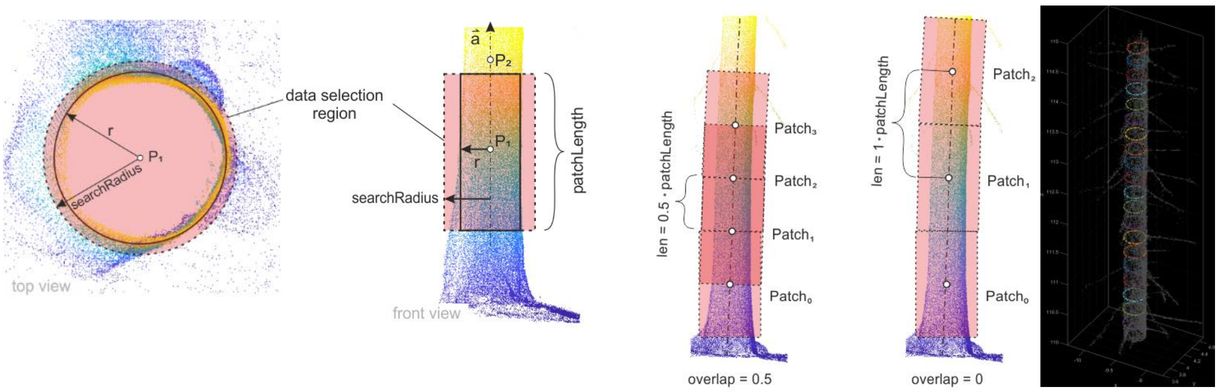
very high-resolution datasets from Unmanned Aerial Vehicles (UAV) as they play an important role in vegetation studies (Glira et al. 2017 and 2020). After strip adjustment, quality control is repeated to double check the remaining height residuals in overlapping areas or compared to external reference data. For the ULS dataset of an alluvial forest at the Pielach River in Lower Austria used by Wieser et al. (2018) for diameter at breast height (DBH) estimation, Glira et al. (2016) achieved a 25% reduction of the height discrapancies from originally 1.8 cm to 1.3 cm after strip adjustment. This can be considered the state of the art, and a further improvement of accuracy would require improvement of multiple components of ULS. However, "of the shelf" ULS missions often do not reach this accuracy.

2.2. Single Tree Modelling using TLS

In recent years, TLS has become the standard method for precise non-destructive three dimensional detection of trees. Commonly the data are acquired from multiple scan positions. Based on the co-registered point clouds different tree parameters can be derived. The most important tree parameters are tree height and DBH.

The opalsDBH module was developed for modelling individual tree stems. It features both estimation of DBH and modelling of full stems or branches by progressively robustly fitting cylinders or cones along the stem axis. Since the algorithm is fully 3D, opalsDBH can model vertical, slanted or even horizontal tree stems (deadwood, driftwood, etc.). Starting from a given approximate 3D location and axis direction, the module incrementally follows the tree stem in both directions if needed (Figure 1). The approximate 3D locations are derived by applying a voxel analysis. As output, the stem diameters for defined height intervals are derived as shown in Figure 2. Taper functions can be generated based on the stem diameters and the extracted tree heights. The data shown in Figure 1 is part of a coniferous dominated plot located in north-east Austria. The TLS acquisition was carried out in May 2017 using a Riegl VZ-2000 (RIEGL Laser Measurement Systems, Horn, Austria). Details on this data set can be found in Bruggisser et al. (2020). The entire processing chain starting with the co-registered point cloud and ending with the derived stem diameters along the stem can be carried out fully automatically.

Figure 3: Left: cross section of a stem point cloud overlaid with the search cylinder for selecting the



points considered for cylinder or cone modelling directly; Middle: trace models with different overlap settings; Right: stem diameters derived via cylinder fittings.

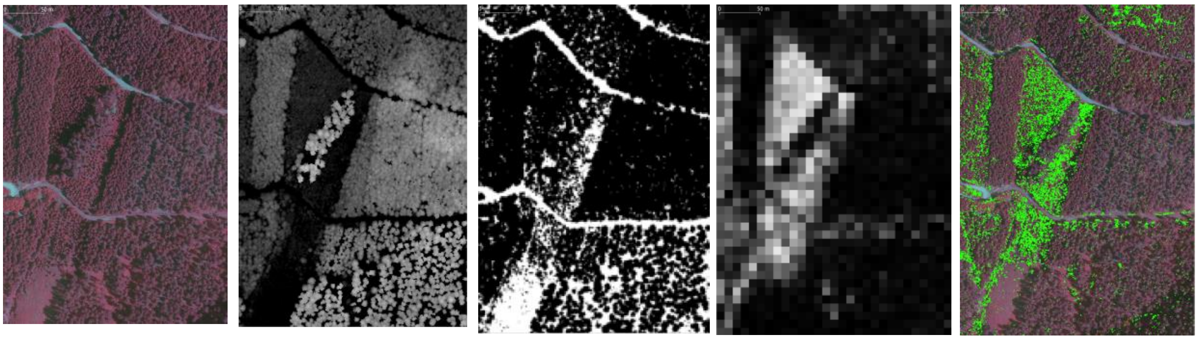
2.3. Country-wide processing of ALS data for deriving forest parameters

For country-wide applications it is beneficial to do tile based processing. Splitting input data into independent data tiles (with or without overlap) is a standard task within OPALS. Tiling limits the computational burden if re-computing becomes necessary, e.g., because of failure or crash due to network problems or other reasons. Even more importantly, processing can be distributed over multiple computers or nodes of a high-performance computing cluster if needed. In this showcase topographic models and forest structure parameters are derived for a ~17 000 km² study area in Austria. The ALS data was acquired within a district-wide ALS campaign carried out between 2008 and 2012 and consists of 6,219 individual ALS flight strips.

Starting from the georeferenced point clouds, the ALS data are split into 3,327 tiles with an extent of 2.2 x 2.2 km². The overlap between neighbouring tiles was set to 100 m. The digital surface model (DSM) was calculated with the opalsDSM module, which calculates the height of a DSM grid cell using the highest 3D point per raster cell for rough surface parts and moving least squares interpolation for smooth surfaces (Hollaus et al., 2010). The derived DSM delivers good results for canopy surfaces as well as for forest gaps. Furthermore, the normalized digital surface model (nDSM) was calculated by subtracting the digital terrain model (DTM) from the DSM. All these topographic models were processed with a spatial resolution of 1 x 1 m².

Based on the nDSM, forest gaps were derived by applying a height threshold and morphological image operations. Furthermore, the normalized point clouds were used to calculate the fractional cover by calculating the ratio between terrain and all points. Finally, parameters describing the vertical forest structure were derived from the point cloud by applying a voxel approach. The derived structural layers contain information about the availability and density of understorey but also about the vertical distribution of the canopy layers. Figure 2 shows exemplary subsets of the derived products.

Figure 2: from left to right: CIR orthophots, nDSM (black = 0 m, white >50 m); gap map (white = gaps,



black = no gap); fractional cover (black=0%, white = 100%); vertical layer between 1 and 2 m (green = voxel with vegetation filled) overlaid to the NIR orthophoto.

3. Summary and Outlook

OPALS is a modular and efficient software package for processing 3D point clouds from arbitrary sensors. As demonstrated by the three showcases, it contains a variety of tools for forest applications at different scales. A detailed list of vegetation related scripts and modules can be found on the opals homepage[2]. Furthermore, OPALS provides advanced tools for fine georeferencing and system calibrations at the highest possible accuracy level.

The modular structure allows distributed processing for optimal processing speed in case of huge projects, as e.g. the country-wide ALS showcase was computed on multiple high-end workstations. Furthermore, the Linux version of OPALS has successfully been used, to process large projects on the Vienna Scientific Cluster 3 (Otepka et al., 2019).

OPALS is currently developed to reach version 3, which will bring two major improvements: The flexibility of spatial neighborhood definitions in point clouds has been largely improved and multi-band raster files are now supported to the full extent and in a uniform way. OPALS version 3 will be released in summer 2021.

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[2] https://opals.geo.tuwien.ac.at/html/nightly/pkg_opalsForest.html

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