COLORIZING THE CLOUD – ADDING RGB INFORMATION TO LIDAR POINT CLOUD FROM AERIAL IMAGERY

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ABSTRACT

Remote sensing products from photogrammetry and lidar scanner have the potential to create a rich dataset when combining information from both sources. This paper presents a first option for the Airborne Snow Observatory (ASO) to couple lidar with the aerial imagery taking with every flight by incorporating the images into the data processing workflow. The image information is matched for each individual point in the point cloud based on their coordinates. Combining and making use of all the recorded information per flight ensures maximum utilization of all available data and can open up research opportunities. (KEYWORDS: Lidar, point cloud, RGB, Structure from Motion, snow depth)

BACKGROUND

The Airborne Snow Observatory project (ASO) is coupling lidar scanning with an image spectrometer to measure snow albedo and snow depth on watershed scale (Painter et al., 2016), and the resulting datasets enable generation of high spatial resolution digital elevation models (DEM). Snow depth values for a basin are derived by subtracting a snow-on DEM from a snow-free DEM and the difference between surface elevation in both DEMs is considered the measured snow depth (Prokop, 2008; Hopkinson et al., 2012). Reported uncertainties of snow depth measurements for airborne laser scanners (ALS) range between 2 and 30 cm for vertical depth while horizontal resolution values of less than $1m^2$ are common (Grünewald et al., 2010; Painter et al., 2016). The high accuracy for retrieved snow depth is also important when it is used as input data to calculate snow water equivalent (SWE) (Raleigh and Small, 2017) or compare with other remote sensing outputs (Bair et al., 2016).

Inside the lidar instruments on the aircraft is also a high-resolution camera that couples each flight path with corresponding RGB images. These images however are currently not part of the data processing pipeline of ASO and only used to determine whether there was any visual interference in form of clouds between the lidar scanner on the airplane and the ground surface. Aside from verification purposes, the images provide a potential source for extending the visual information for each point measured by the scanner. The output data format of lidar is commonly distributed in the standardize laser file format LAS by the American Society for Photogrammetry & Remote Sensing (ASPRS; https://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf). The specification has a pre-defined format for each recorded data point that also includes information for the Red, Green and Blue (RGB) value which an image can provide. Thus, combining the information from lidar with the images seems a natural improvement for the ASO data processing workflow and will be the focus of this paper.

METHODS

Data Recording Setup

ASO has been operating since 2013 and is flying on weekly basis during the melt season for the surveyed alpine environments. The airplane carries a Riegl VG-1560 lidar instrument which has two offset lidar scanners plus a high-resolution camera. The offset of the scanners improves the distribution and retrievals of measurements in complex terrain or varying topography (Figure 1). The camera records images by a fixed interval, which is currently set to twelve seconds for ASO. The instrument is further coupled with an inertial measurement (IMU) and GPS unit to record coordinates of the flight line and the pitch, roll, and yaw of the airplane. Each flight is completed in a "lawn mower" pattern from North to South with one cross section flight from East to West to ensure 100% coverage of the area and minimize systematic offsets and errors (Painter et al., 2016) (Figure).

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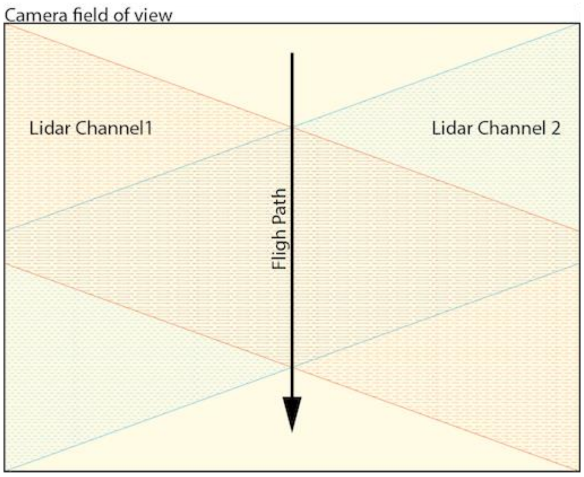

Figure 1. Lidar offset and camera field of view

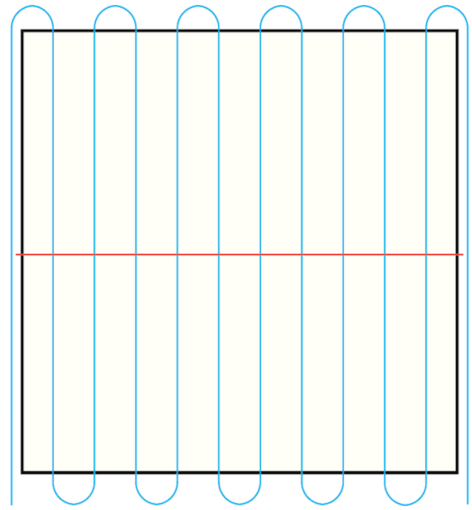

Figure 2. Flight path in 'lawn mower' pattern (blue) with cross-section (red)

Revised Workflow

Post processing of the lidar data is currently done using the Riegl software and produces a LAS output file for each flight line. To add the RGB information to each point, the revised workflow first combines all lines into one file to create a point cloud for the entire study area. Next step is to couple the IMU and GPS information with the imagery, which is done by matching the recorded timestamps from the images to a data entry recorded in the Smoothed Best Estimate of Trajectory (SBET; https://www.applanix.com) file of the IMU. The geo-referenced pictures are then used in Agisoft Photoscan (http://www.agisoft.com) to create a GeoTIFF from all the individual images. The exported orthophoto is projected into the local time zone of the study area in WGS 84 since that is the projection the Riegl software is using for the lidar point cloud. For the last step, the RGB information of the

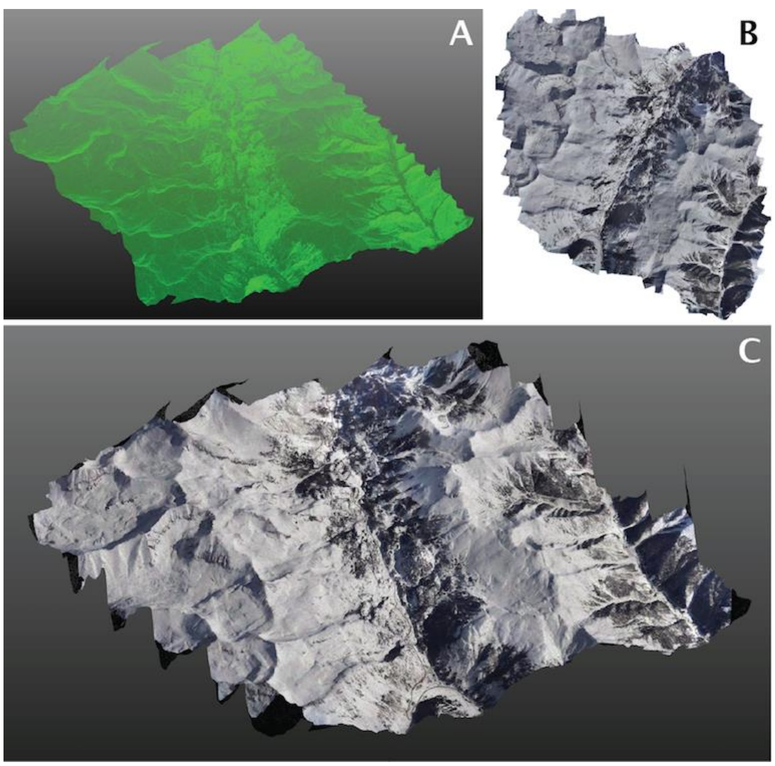

Figure 1. Colorizing the point cloud, starting with the lidar cloud (A) over creating the geo-referenced orthophoto (B) to combining both products (C).

orthophoto is added to the basin wide point cloud with the open source software PDAL (https://www.pdal.io) where the points are matched by the x and y coordinates and the values are added to each individual point of the cloud. The result of the process is visualized in Figure 3 going from raw point cloud to colorized product adding the orthophoto RGB values.

Agisoft Photoscan is at its core a Structure from Motion software (SfM) which produces a 3-D model of an object or area of interest. SfM has been increasingly used in the geoscience community as a cost-effective alternative to create a DEM from imagery (Westoby et al., 2012) and also applied for snow depth measurements using a manned aircraft with accuracies between 8 and 30 cm (Nolan et al., 2015) or unmanned aerial systems (UAS) with root mean square errors between 7 and 30 cm (Bühler et al., 2016). The orthophoto in this workflow is a product of the independently reconstructed point cloud by Agisoft using only the images and the IMU information. The point cloud can be exported in the LAS format in a separate step and create a one to one comparison opportunity between lidar and SfM, plus a way for evaluating the accuracy of point matching of the orthophoto and the lidar point cloud. The comparison between Structure from Motion and lidar LAS files is performed by using the X, Y and Z information for each point. Both software products calculate the values independently from each other, which requires additional analysis on how closely they match. Lidar will be treated as the reference system to which SfM should match up. The SfM point cloud has the advantage of already holding the RGB information for each point plus being much higher in density.

Point Cloud Comparison

For an initial assessment of the difference between the point clouds an excerpt in the upper left corner of the study area was chosen and a DEM was produced with each software product. The point count for SfM was 84 Million versus 28 Million for lidar. The SfM DEM showed a slight overestimation in the Z direction which will need further investigation (Figure 4). Among of the reasons for the overestimation could be re-constructing challenges due to shading, illumination, and view zenith angles of the photos. The pictures were not taken a SfM pipeline in first place and have some potential for improvements. Other suspected cause is that only a few images of the region were selected and not the entire area. Using all of the images is expected to help Agisoft with calculating the geometry by having more data points to operate on. SfM also has the option to set GPS information based on ground control points (GCP) in the scenes, which could additionally improve the accuracy of the orthoimage and influence the comparison results. This step has not been incorporated and is another option for trying to match the lidar point cloud.

DISCUSSION AND CONCLUSION

Next steps in re-defining the workflow is to fully automate and establish methods to quantify the quality of matching the point cloud points. The quality measures range from statistical standard error analysis of the coordinates to evaluating on how errors could be introduced in the system. Other considerations for the process is the file format of the images which are currently in the raw proprietary format iiq. This format is the default of the embedded camera of the lidar scanner provided by Phase One (https://www.phaseone.com) and specific to their product line. For the initial workflow implementation, the files were converted to a 16-bit TIFF format and additional analysis will be required to see whether the input quality needs to be that high and what the resulting quality effects this has for the orthophoto of the area.

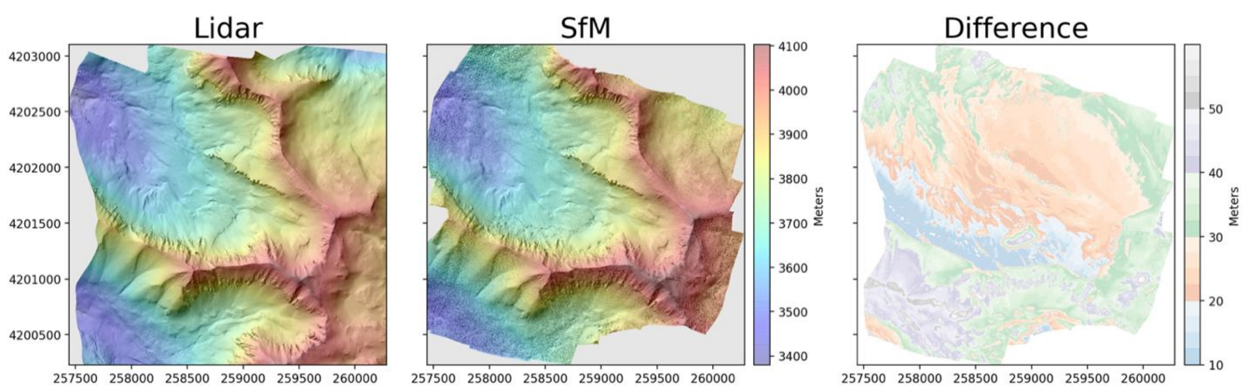

Figure 2. Comparison of lidar and SfM

A better understanding and confidence for the quality of matching the RGB information to points in the cloud further opens up opportunities to analyze the lidar data. This could for instance be to investigate whether there is a correlation between intensity and RGB values or verifying the classification of the lidar measurement. Long range evaluation is also on whether imagery can be used as an alternative to create point clouds versus a lidar scanner or combining both point clouds for even higher resolution.

Overall the initial result and implementation are very promising and present a first use case for the ASO aerial imagery beyond a simple verification tool. A robust data processing workflow that incorporates these with known quality opens up the opportunities for new research. Using the images as an alternative for creating high spatial resolution point clouds using Structure for Motion could further improve existing data sets for snow covered areas.

REFERENCES

Bair, E. H., K. Rittger, R. E. Davis, T. H. Painter, and J. Dozier. 2016. Validating reconstruction of snow water equivalent in California's Sierra Nevada using measurements from the NASA Airborne Snow Observatory. *Water Resources Research* 52 (11):8437–8460.

Bühler, Y., M. S. Adams, R. Bösch, and A. Stoffel. 2016. Mapping snow depth in alpine terrain with unmanned aerial systems (UASs): potential and limitations. *The Cryosphere* 10 (3):1075–1088.

Grünewald, T., M. Schirmer, R. Mott, and M. Lehning. 2010. Spatial and temporal variability of snow depth and ablation rates in a small mountain catchment. *The cryosphere* 4 (EPFL-ARTICLE-170338):215–225.

Hopkinson, C., T. Collins, A. Anderson, J. Pomeroy, and I. Spooner. 2012. Relationships between snowpack depth and primary LiDAR point cloud derivatives in a mountainous environment. *CANADIAN WATER RESOURCES JOURNAL* 37 (2):69–87.

Nolan, M., C. F. Larsen, and M. Sturm. 2015. Mapping snow-depth from manned-aircraft on landscape scales at centimeter resolution using Structure-from-Motion photogrammetry. *The cryosphere discussions TCD.* 9 (1):333–381.

Painter, T. H., D. F. Berisford, J. W. Boardman, K. J. Bormann, J. S. Deems, F. Gehrke, A. Hedrick, M. Joyce, R. Laidlaw, D. Marks, C. Mattmann, B. McGurk, P. Ramirez, M. Richardson, S. M. Skiles, F. C. Seidel, and A. Winstral. 2016. The Airborne Snow Observatory: Fusion of scanning lidar, imaging spectrometer, and physically-based modeling for mapping snow water equivalent and snow albedo. *Remote Sensing of Environment* 184:139–152.

Prokop, A. 2008. Assessing the applicability of terrestrial laser scanning for spatial snow depth measurements. *Cold regions science and technology* 54 (3):155–163.

Raleigh, M. S., and E. E. Small. 2017. Snowpack density modeling is the primary source of uncertainty when mapping basin-wide SWE with lidar: Uncertainties in SWE Mapping With Lidar. *Geophysical Research Letters* 44 (8):3700–3709.

Westoby, M. J., J. Brasington, N. F. Glasser, M. J. Hambrey, and J. M. Reynolds. 2012. 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology* 179:300–314.