Working with 3D photogrammetric point clouds and 2D high-resolution orthophotos: Summary notes from the Applied Geospatial Research Group (U of C)

Note: This document summarizes the experiences and opinions of members of the Applied Geospatial Research Group (AGRG – www.appliedgrg.ca) in the Department of Geography, University of Calgary, as well as published, peer-reviewed papers. The majority of point cloud work in the AGRG lab employs imagery captured by drone (i.e., Unmanned Aerial Vehicle/UAV), which was often planned and executed by the lab members themselves.

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NOTES ON SOFTWARE

SfM Software

- Lab members have used both Agisoft PhotoScan and Pix4D for creating 3D photogrammetric point clouds (PPCs) and 2D high-resolution orthomosaics
- Opinions vary on which is best
- One, a post-doc, uses drone imagery and extracted 3D PPCs to look at glacial surfaces and changes in glacial surface with PhotoScan, and has not found an advantage to Pix4D
- However, two others in the lab – one technician and one PhD - who have equal levels of experience with our post-doc (though for different applications – forest environments, and shrubby grasslands) have moved from PhotoScan to Pix4D and find it works better for them
- From one of our technicians who has notable experience in both software packages, here are pros and cons of each according to him:
    - Agisoft PhotoScan

        - Works better when photos don’t come with photo centre locations (and the software has to align completely on its own)
        - You buy a license for it once and have it
        - But, have found that when making orthomosaics there tend to be more data gaps where overlap doesn’t meet the PhotoScan standards (but it’s a black box, and don’t know exactly what these are)
        - There is less technical support
        - 3D PPC point densities tend to be lower
    - Pix4D
        - Does not work as well when photo centre locations aren’t known
        - Is a yearly maintenance fee on top of the base subscription – ongoing costs
        - Orthomosaics produced do not have the same data gaps as from PhotoScan
        - Is a more standardized software with better user support
        - There are more parameters and settings (which could be good or bad – may be too many for some applications)
        - Has a cloud-based version (processing can be run on the cloud)
        - 3D PPCs generally have several times higher the point densities; these may not increase the accuracy of the point cloud (but anecdotal observations have been that at least some of this extra information does increase accuracies)
- The vast majority of publications from members of the lab have used PhotoScan

3D PPC Analysis Software

- Working with and analyzing the 3D PPCs themselves generally involves multiple software packages (or open-source custom coding) – no one software appears to do everything needed

- The most common are: LAStools (https://rapidlasso.com/lastools/), CloudCompare (https://www.danielgm.net/cc/), custom Python scripts using existing packages, and Esri’s ArcGIS

- LAStools
    - Purchased software, built for working with LiDAR point clouds but can be applied to PPCs
        - There is a “free” version, but it adds in stochastic noise to datasets so as to encourage you to use the purchased version
    - Used by lab members mainly for: noise and error removal (automated and manual), classifying ground points, and for tiling large point cloud datasets
- CloudCompare
    - Free, open-source software
    - There is a Python interface available, for customizing use
    - Has an abundance of tools for working with point clouds, and for visualizing them

    - Has been mainly used for: comparing PPCs (e.g., for glacial studies), noise and error removal, change detection
    - There are some good forums online for help and ideas
- ArcGIS
    - Has a LAS Dataset functionality for working with point clouds
    - Not great for manipulating the point clouds themselves, but more for converting point clouds with classified points into Digital Terrain Models and Digital Surface Models
- Python
    - For custom analyses that cannot be performed otherwise, Python is most commonly used among lab members
    - Packages for working with point clouds/images include: laspy, numpy, open3d, opencv, pclpy, RSGISLib, orfeo toolbox
- Other software
    - There has been some use of Harris Geospatial's ENVI (https://www.harrisgeospatial.com/Software-Technology/ENVI) software and its LiDAR extension, but only a little as it doesn't handle large point clouds well

Image Analysis Software

- Most orthophotos/orthomosaic image analysis in the lab is done with either ArcGIS, ENVI, or with custom Python scripts
- The lab used to have access to eCognition for image segmentation analyses, but our department no longer supports it; as an alternative, lab members have used tools in ENVI
- Because the 3D PPCs are hard to work with themselves, when it is possible to convert point clouds to raster and work with this (as a digital terrain model [DTM] or digital surface model [DSM], or as a canopy height model [CHM]; or even as an intensity layer), lab members tend to do so
    - Rasters are far easier to work with than point clouds
- Also, when point clouds are analyzed directly, the outputs tend to be raster anyway (since these then often feed into other analyses or models)

Other Software

- For visualization, FugroViewer (https://www.fugro.com/about-fugro/our-expertise/technology/fugroviewer) is a free software that works well for visualizing point clouds

LESSONS LEARNED

Creating 3D PPCs and Orthomosaics

- A high amount of side-lap and forward/end-lap is important for good quality PPCs
  - I.e., 80%+ end-lap, and 60%+ side-lap (though having even higher end-lap, of 90%+, can compensate to a degree for lower side-lap)
- Sufficient number of evenly-distributed (or systematically-distributed) ground control points that are visible in multiple images and geolocated with high-precision, high-accuracy GPS (i.e., RTK GNSS) are essential for having good geolocational accuracy of PPCs – especially if want to compare or integrate with other PPCs or LiDAR later on
  - The size, shape, and colour of these GCPs influences their visibility and photo/object matching abilities within SfM software – clear bullseye or indication of 'centre' of GCPs is good, as is variety in colours (so matching them up is more accurate)
  - Ground sample distance (spatial resolution) of the drone imagery also plays a role
  - If tiling large datasets for processing, ensure at least 3 GCPs are shared between overlapping tiles (for proper alignment of the tiles in x, y and z directions)
- Leaf-on imagery best for estimating vegetative/canopy characteristics; leaf-off imagery better for extracting ground surface/terrain
- Unchanging light conditions are important for best PPC creation/construction; diffuse (cloudy) or high-angle direct works best for vegetated surfaces so as to minimize deep shadows, while low-angle, direct light works best for snowy surfaces so as to maximize surface feature contrast and texture
- Ground sample distances of ~6cm or less (in images) generally used, for looking at vegetation with the detail of lab members' work
- Work with creating shadow-free orthomosaics using imagery from before and then after solar noon worked successfully; though these ideally taken within a few days of one another (to avoid phenological differences) – can be useful for filling gaps made by shadows
  - *Rahman, M. M., McDermid, G. J., Mckeeman, T., & Lovitt, J. 2019.* ***A Workflow to Minimize Shadows in UAV-based Orthomosaics. Journal of Unmanned Vehicle Systems****. Journal of Unmanned Vehicle Systems, 7(2): 107-117.*
- Areas of dense vegetation result in understory or ground occlusion in photos, and canopy height models in these areas from PPCs can be trickier/less accurate
- Steeper or more complex topography lowers PPC-based terrain model accuracies
- The quality of a canopy height model is very dependent on the accuracy of the digital surface model, and most especially, the digital terrain model

Working with 3D PPCs and Orthomosaics

- Converting PPCs to raster where possible and then working with the resulting rasters is far easier than working directly with the PPCs themselves

- No one software does everything you need or want it to do – always tends to be a combination of software tools

- Both the PPC elevation/height data and the spectral data that comes along with it can be handy in mapping or modeling vegetation attributes or characteristics

PUBLISHED PAPERS & APPLICATIONS

[*In order from most recent to least recent; please see the original publications for full details, as these descriptions are not comprehensive.*]

Bash, E.A., Moorman, B.J., Menounos, B., & Gunther, A. 2020. ***Evaluation of SfM for surface characterization of a snow-covered glacier through comparison with aerial lidar****. Journal of Unmanned Vehicle Systems 8: 119-139.*

- Authors examine UAV image-based PPC accuracy and precision assessments, looking at levels and distributions of precision and errors in PPCs when compared to ground control points, and when compared to a LiDAR dataset. This is done over a snow-covered glacier. They show the importance of rigorous and standardized precision and accuracy assessments, and the influence of illumination conditions and surface texture on PPC reconstruction success and accuracy over snowy surfaces. The authors recommend direct, low-angle light for increasing surface feature contrast over these surfaces, while also emphasizing the need for consistency in illumination conditions between flight acquisitions.

Poley, L.G., & McDermid, G.J., 2020. ***A systematic review of the factors influencing the estimation of vegetation aboveground biomass using Unmanned Aerial Systems****. Remote Sensing, 12(7): 1052.*

- The authors review factors influencing aboveground biomass estimation using drones. Most studies reviewed used DTMs, DSMs, and CHMs as inputs or for extracting inputs for models. Structural , multispectral, textural and other types of inputs are used in modeling, but combining different types was most effective. Review found no influence of fixed-wing vs. multirotor platforms on biomass estimate accuracy results, but did find that the angle of image collection impacts the accuracy of DTMs and DSMs – the greater overlap and variety in viewing angles of oblique angles was shown to improve PPC precision and accuracy. Higher ground sample distances also improved accuracy and precision of PPCs. Flight patterns were found to be important in that high levels of overlap increased PPC quality, and the authors recommend flying more than one's study area so as to account for increased errors along edges.

Poley, L.G., Laskin, D.N., & McDermid, G.J., 2020. ***Quantifying aboveground biomass of shrubs using spectral and structural metrics derived from UAS imagery****. Remote sensing 12(14): 2199.*

- The authors use orthomosaics and PPCs from drone-based imagery to model aboveground biomass of shrubs in a montane environment. They combine structural and spectral variables in their models, showing a combined spectral-structural metric worked a nearly as well as a multiple variables combined. The authors urge caution when extracting spectral metrics from commercial-grade digital camera imagery that are not radiometrically corrected, particularly under changing illumination conditions.

Dietmaier, A., McDermid, G.J., Rahman, M.M., Linke, J., & Ludwig, R. 2019. ***Comparison of LiDAR and digital aerial photogrammetry for characterizing canopy openings in the Boreal Forest of Northern Alberta****. Remote Sensing 11 (16), 1919.*

- Authors do a comparison of LiDAR point clouds and PPCs from airborne imagery (5.5 cm ground sample distance), and showed LiDAR-based canopy height models outperformed PPC-based canopy height models in detecting and mapping small canopy openings (i.e., canopy gaps).

*Rahman, M.M., McDermid, G., & Lovitt, J. 2017****. A new method to map depth to groundwater table in peatland using Unmanned Aerial System (UAS) and photogrammetric techniques****. Remote Sensing 9(10), 1057.*

- The authors developed a successful workflow for estimating depth to ground water using drone/aerial imagery and PPCs, for use in areas with very little ground slope and regular open water features (e.g., in a peatland). They also then applied this to another study area and it worked.

Queiroz, G.L., McDermid, G.J., Castilla, G., Linke, J., & Rahman, M.M. 2019. ***Mapping Coarse Woody Debris with Random Forest Classification of Centimetric Aerial Imagery****. Forests, 10(6): 471.*

- The authors successfully used airborne imagery (RGB and NIR) and LiDAR to map coarse woody debris as snags and logs in orthomosaics (with 5 cm ground sample distances). They used segmentation in eCognition and then random forest for classification of objects, and found that NDVI variables were of high importance to classification accuracy, as were variables derived from the canopy height models. They observed a trade-off between leaf-on and leaf-off data: the former was better for distinguishing live from dead vegetation but the latter enabled better penetration below the canopy. The authors recommend using 100+ training samples if simply identifying coarse woody debris and 1000+ training samples if distinguishing between snags and logs.

Queiroz, G.L., McDermid, G.J., Linke, J., Hopkinson, C., & Kariyeva, J. 2020. ***Estimating Coarse Woody Debris Volume Using Image Analysis and Multispectral LiDAR****. Forests 11 (2), 141.*

- The authors successfully modeled coarse woody debris volume, with aerial imagery, LiDAR, and multispectral LiDAR. They used latter to derive sub-canopy vegetation indices based on intensity values, which appeared to help in accounting for occluded woody debris. Important model inputs included wetland probability, maximum tree heights, canopy cover, area of visible woody debris, variability in vegetation indices, and area of visible water. The authors suggest including leaf-off imagery in future work.

Bash, E.A., Moorman, B.J., & Gunther, A. 2018. ***Detecting short-term surface melt on an arctic glacier using UAV surveys****. Remote Sensing, 10: 1547.*

and

Bash, E.A. & B.J. Moorman. 2020. ***Surface melt and the importance of water flow - an analysis based on high-resolution unmanned aerial vehicle (UAV) data for an Arctic glacier****. The Cryosphere 14: 549-563.*

- The authors used drone imagery and PPCs to examine arctic glacier surface melt and water flow. They found that image ground sample distance had a large impact on PPC accuracy, as did GPS unit precision/accuracy. They also proposed some standard procedures for creating, evaluating and comparing PPCs within context of this work.

Fromm, M., Schubert, M., Castilla, G., Linke,J., & McDermid, G.J. 2019. ***Automated Detection of Conifer Seedlings in Drone Imagery Using Convolutional Neural Networks****. Remote Sensing 11 (21), 2585.*

- The authors employ very high resolution imagery for detecting and measuring conifer seedlings, using low-altitude drone imagery (5 m flight altitude) and 0.3 cm ground sample distances. They used object detection and convolutional neural networks, wherein pre-training and data augmentation improved results, as did including images from both leaf-on and leaf-off conditions. Higher spatial resolutions also improved results. The authors found that all methods worked reasonably well on medium or larger seedlings, but only one of tested methods worked for small seedlings.

Chen, S., G.J. McDermid, G. Castilla, & Linke, J.. 2017. ***Measuring vegetation height in linear disturbances in the boreal forest with UAV photogrammetry****. Remote Sensing, 9(11): 1257.*

- The authors evaluated use of drone PPCs for estimating vegetation height on linear disturbances, and found that for their work integration of LiDAR terrain did not improve canopy height models. The drone data approach worked similarly to LiDAR data approach when examined at plot level.

Lovitt, J., Rahman, M.M., & McDermid, G.J. 2017. ***Assessing the value of UAV photogrammetry for characterizing terrain in complex peatlands****. Remote Sensing 9: 715.*

- The authors demonstrated use of drone PPCs for characterizing complex terrain in peatlands (hummocks/hollows). They found that drone PPCs and drone PPCs filled in with LiDAR in gaps performed similarly, but LiDAR alone performed significantly worse in capturing complexity. Performance varied with terrain complexity and level of vegetation (dense upland pockets showed worst performance because of occlusion of the terrain). The authors suggest point densities in excess of 30-50 pts/m^2 for effectively capturing microtopography in peatlands.