Progress towards Mapping Seasonal Snowpack from Very High Resolution Drone Photogrammetry

Todd Redpath, Pascal Sirguey, Nicolas Cullen, Julien Boeuf and Sean Fitzsimons
University of Otago
Dunedin, New Zealand
todd.redpath@postgrad.otago.ac.nz

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Introduction

Remotely piloted aircraft systems (RPAS) offer the opportunity to map small areas photogrammetrically at very high resolution in an on-demand fashion. RPAS datasets may subsequently provide very high resolution three dimensional terrain and surface models. While the use of RPAS for both qualitative and quantitative mapping is increasing rapidly, examples related to snow are promising, but limited (De Michele et al. 2015; Durand 2015; Bühler et al. 2016; Harder et al. 2016; Marti et al. 2016).

Seasonal snow provides an important resource globally (Mankin et al. 2015), and is variable in space and time (Clark et al. 2011). The current study aims to better understand spatial and temporal variability in seasonal snow cover, and the water resource it provides. To this end, a campaign of winter photogrammetric surveys of a small alpine basin in the Pisa Range, Central Otago, is being undertaken using RPAS.

This paper focuses on the process of retrieving snow depth via RPAS photogrammetry. Associated challenges include minimising spatial uncertainties sufficiently to reliably detect changes in snow depth over time, while also reducing the need for extensive in-situ collection of ground control points (GCPs. Achieving this will resolve the 4-dimensional (space + time) variability in snow depth with detail not seen before, providing new improved insight into influential processes.

Determination of snow depth via RPAS photogrammetry relies on the principal of differencing between temporally subsequent digital surface models (DSM) (Durand 2015; Harder et al. 2016). A snow-free DSM provides a reference dataset for absolute snow depth, while changes in snow distribution through winter may be assessed by comparing DSMs obtained while snow cover is present in the basin.

Data and Methods

The study basin (Fig. 1), a tributary of the Leopold Burn, is 0.41 km² in size, and is located in the Pisa Range, Central Otago. Elevation of the basin ranges between 1440 and 1580 m a.s.l. The basin runs more or less North to South, with slopes of Western aspect dominating the basin area.

A baseline RPAS flight was carried out in May 2016. The area of interest (0.875 km², encompassing the study basin in its entirety) was flown in a single flight. Flight time was...
approximately 35 minutes, with 885 overlapping photos being captured by a Sony NEX-5R camera mounted in a Trimble UX-5 RPAS. A total of 23 GCPs were set out and surveyed across the area of interest (Fig. 1), facilitating a high quality photogrammetric triangulation. Typically, GCP collection involves surveying the position of target mats, painted with a contrasted pattern, and distributed around the study area. Surveying is done by RTK GPS, which minimises the occupation time required for each GCP. The distribution of target mats, and their retrieval following the RPAS flight is labour intensive and time consuming, particularly in alpine environments.

Figure 1. Topographic map of the field site showing the locations of surveyed and synthetic GCPs and the imaging area of interest (AOI) for RPAS flights.

In order to mitigate the time consumed collecting GCPs, alternative approaches to generating synthetic GCPs from the reference DSM have been evaluated. The alternative approach involves determining \( x, y \) and \( z \) (i.e., N, E and elevation) coordinates for prominent schist tors, which are common through the study area, from the reference DSM, providing a new set of synthetic reference GCPs for use in subsequent photogrammetric processing. It is expected that features used as synthetic GCPs will generally remain snow-free as a snowpack develops within the catchment, and will remain apparent in imagery acquired throughout the winter season.

The alternative approach has been assessed by using a set of synthetic GCPs to carry out new triangulations of the data from the baseline flight, while the original surveyed GCPs are retained only as check. Once the triangulation using synthetic GCPs is complete, the resulting (synthetic GCP) DSM can be compared to the reference DSM by considering the difference between the two raster datasets, which possess the same spatial resolution and extent. The approach provides insight into the magnitude of elevation difference that could be reliably detected and interpreted as a change in snow depth, rather than uncertainties associated with triangulation of the image block.
Results and Discussion

Relative to the surveyed GCPs, overall RMS errors for the base flight were 0.02 m, 0.02 m and 0.01 m in the x, y and z directions respectively. Maximum residuals for the GCPs were 0.05 and 0.07 m in the x and y directions, respectively. Importantly, the triangulation yielded a maximum vertical residual of 0.03 m, which is promising for the future detection of changes in snow depth. Output products from the triangulation included an RGB ortho-mosaic with a spatial resolution of 0.04 m, and a DSM with spatial resolution of 0.15 m. The very high spatial resolution achieved provides promising data-product for assessing spatial and temporal variability in the seasonal snow cover over the course of a winter season.

Comparison between the reference and synthetic GCP DSMs was determined simply as $DSM_r - DSM_s$, where $DSM_r$ is the reference DSM and $DSM_s$ is the DSM produced using the synthetic GCPs. This comparison provided a mean residual for all cells of -0.146 m ($\sigma_1 = 0.122$ m), indicating a positive vertical bias of $DSM_s$ relative to $DSM_r$ (Fig. 2). The distribution of the residual, however, was found to be bi-modal (Fig. 2), and exhibited spatial trends indicative of sub-optimal solution of the photogrammetric problem within the processing software (Fig. 3). The spatial distribution of the residual appears to be controlled by the distribution of the synthetic GCPs.

Figure 2. Histogram for the residual determined by $DSM_r - DSM_s$ for all DSM cells.
Spatial trends are particularly apparent in Figure 4 which exhibits contrasting departures between $DSM_s$ and $DSM_r$ when considering the residuals for cells inside and outside of the study catchment separately. Within the study catchment, the mean residual reduces to $-0.079 \text{ m} (\sigma_1 = 0.086 \text{ m})$, while for cells outside the study catchment, the mean residual is $-0.186 \text{ m} (\sigma_1 = 0.125 \text{ m})$. Residual variation relative to the GCP distribution
suggests that the performance of the triangulation at a pixel level depends on the location of a pixel in terms of the GCP distribution, whereby interior cells (those that are surrounded by the GCP network) are better constrained by the photogrammetric triangulation. Conversely, exterior cells (those that lie outside the GCP network) have greater exposure to error propagated by a sub-optimal solution. Remaining vertical bias may be due to systematic bias in interpreting conjugate points on schist tors.

![Figure 4](image.png)  

**Figure 4.** Histograms for the residual determined by $DSM_r - DSM_s$ cells within the study catchment (A) and cells outside the study catchment (B).

**Conclusion**

These results highlight the importance of operators understanding well the software implementation of photogrammetric processing when designing surveys, but also suggest that satisfactory results can be obtained using only synthetic GCPs derived from a reference DSM. Accurate results, however, can only be expected within the support of GCP network geometry. While further testing is required in order to optimise the number and placement of GCPs, the current residuals for DSMs are already approaching a magnitude whereby the DSM could be used to determine absolute snow depth. In addition, this approach provides a simplified platform for effectively monitoring changes in snow depth over time.

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**References**


