

DEM CREATION OF A SNOW COVERED SURFACE USING DIGITAL AERIAL PHOTOGRAPHY

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ABSTRACT:

Seasonal snow plays a vital role in the world's water resources. In some areas, seasonal snow melt provides water for agriculture, industry, hydro-electricity generation and urban water supply. Accurate estimate of the snow depth and its characteristics allows determination of the water content of the snow pack. This determination is very important in water management regimes. This paper presents a component of a research project undertaken in Falls Creek Ski Resort in Victoria, Australia. Snow depth has traditionally been measured using point samples, with an ad hoc distribution across the resort, mainly in areas of interest and extrapolated to give a value of snow depth for an area. Previous efforts to use photogrammetry to create DEMs (Digital Elevation Model) of snow (or glaciers) have used a large ground sample distance (GSD) or small scale photography, and have yielded 1-2 metre accuracies, in the Z component. This has limited use in Australia, where snow depths rarely exceed 3 metres. This paper investigates using high resolution digital aerial photography to create a DEM of a snow covered surface of a small area.

1. INTRODUCTION

1.1 The Project

Snow is, for the most part, a low texture and homogeneous land cover type. In the past, image matching and DEM creations of snow covered terrain have been difficult and unsuccessful for high accuracy height determination.

This paper describes research into the creation of an accurate DEM of a snow covered surface. The desired accuracy for this DEM, based on datasets and environment, is 0.20 meters.

A DEM of a snow surface along with a DEM of the underlying terrain can produce a snow volume estimate. Using a DEM allows estimations to be area based rather than point based. Less interpolation is required when using a DEM since it models the surface, and the network of points used to create a DEM are usually denser than those of manual field point observations.

1.2 Limitations of Traditional Methods

As photogrammetry is a well established technique, its capabilities and limitations are well known. Conventional aerial film photography has been used to create DEMs and orthorectified images for decades. Although film photography had many uses and applications, some applications had known problems. Land cover types that are homogenous frequently cause difficulties.

In a digital environment, when aerial film photography is captured, it is scanned and undergoes a soft-copy photogrammetry process. The process is mostly automated. Scanning a film image, which is a continuous tone medium,

quantises the information into a discrete set of values. This quantisation causes some data to be lost. The number of values is based on the scanner. This is referred to as radiometric resolution. Film photography is usually scanned at 8-bit, which translates to 256 values per band. Although there are scanners available that can achieve 10-bit or even 12-bit radiometric resolution.

Another common limitation in traditional film-base methods is the overlap between adjacent frames. The standard 60% overlap can cause some problems when mountainous terrain is being captured. The displacement of mountain-tops and shadowing caused by the terrain are some of problems that may be encountered with this minimum overlap. Although it is possible to capture an area with multiple overlaps and runs, Leberl and Szabo (2005) outline that it has been previously time consuming and costly when using large format film cameras. More frames leads to more scanning and processing time, therefore increases costs.

Previous efforts using film-based aerial photography have had success when measured against their desired outcomes. Bacher et al. (1999) used aerial photography to create DEMs of glacial areas, to an accuracy of 1-2 metres. The photography used had scale between 1:39,000 and 1:52,000. Using photography at a scale of 1:30,000, Ledwith and Lundén (2001) created DEMs of snow-covered areas in Norway and achieved an average difference of 2.8 metres between derived DEMs and GPS field measurements and maps. Height accuracies in this range are not suitable for an Australian study, as seasonal snow falls rarely exceed 3 metres in depth.

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1.3 Digital Advantage

The development of digital aerial image systems over the last decade has enhanced existing applications and opened up many new opportunities. Regardless of which digital aerial system is used, they supersede tradition film based methods in terms of their spatial, radiometric and spectral resolutions (Weichelt et al. 2005). Specific advantages that aid this research project are an increase in spatial and radiometric resolutions.

High spatial resolution gives more detail and can assist image matching in areas of steep and hilly terrain. Increased radiometric resolution provides more grey levels per pixel, per channel therefore giving wider range tonal differences. This allows greater detail to be seen within shadowed areas, as well as giving homogeneous land cover types a larger data range. Redundant overlap can aid in the bundle adjustment and matching process. These enhancements of the camera system, together with careful flight planning to achieve the desired specifications, are encouraging developments for high accuracy measurements (Wolf and Dewitt 2000).

One limitation of digital camera systems is the rectangular footprint of the image. As the short side of the rectangle is usually along the flight line, the base/height ratio derived from digital photography is lower than that of film photography taken with the similar parameters. A lower base/height ratio affects the geometric accuracy of elevations extracted from the photography. This weakness is balanced by the stable image platform and better image quality (Dörstel 2003).

As mentioned previously, increasing overlap or flight runs when using a film-base system increases costs. An improvement in cost and efficiency is another characteristic of digital camera systems. Since the photography is captured in a digital format it can move through the soft-copy photogrammetric process seamlessly, i.e. no need for scanning photography.

2. METHOD

2.1 Approach to determine snow depth

One approach to determine snow depth using aerial photography requires two DEMs. One, a reference surface (the terrain, assumed to be static), and the second of the snow cover (at a point in time). The displacement of the snow surface from the reference surface is the snow depth over an area. Snow depth determined using such an area-based method should yield a better estimate of snow volume.

2.2 Digital Camera System

The development of digital aerial camera systems over the last decade has provided researchers with a new generation of enhanced imagery able to address previously unsolvable photogrammetric problems and facilitated the development of new applications. In particular, this new digital imagery has a high spatial resolution (potential for up to 5cm GSD) and an enhanced radiometric resolution (12-bits per channel).

The digital camera system used in this project was the DMC (Digital Mapping Camera), flown by AAM Hatch Pty Ltd during the 2007 winter snow season (southern hemisphere). Camera and photography specifications for this project are

presented in Table 1. For detailed camera specifications and description refer to Hinz et al. (2001).

Camera System:	DMC
Focal length:	120 mm
Image Size:	7680 pixels by 13824 pixels
Pixel size:	12 μ m
Time of capture:	\approx 1245 – 1345
Date of capture:	August 20 th , 2007
Photo Coverage:	1720 m by 1540 m
Stereo Coverage:	1480 m by 1540 m
GSD:	8 cm
Total Runs / Frames:	4 / 10
Flying Height:	2500 m AMSL
Terrain Variation:	1570 m – 1760 m
Overlap:	80%*
Scale:	1:6 666

Table 1: Camera, flight and photograph specifications
* This outcome is derived indirectly.

To achieve the 80% overlap, the photography was flown in two sets over the same area, offset from each other about 120m along the flight line. Each set comprised of two runs, with 5 photographs per run. Each set of photographs had a 60% overlap and 60% sidelap. The double set of imagery gave a possible 80% overlap of frames between sets of photography, therefore creating a high level of redundancy. In addition, the 60% sidelap was positioned so that the majority of the study areas would be within this overlap, therefore giving more validation points for the overall photography. This high level of redundancy meant that a point on the ground could be observed on up to 8 photographs. Figure 1 shows the flight plan of the photography.

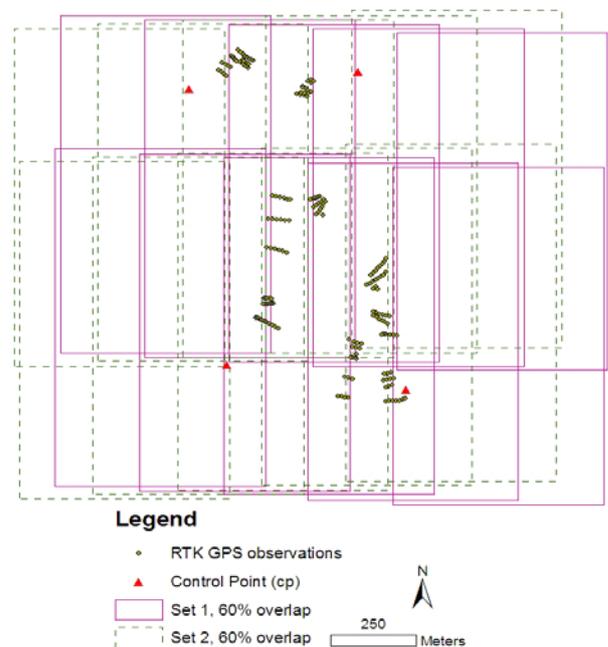


Figure 1: Frame footprints and ground observation locations.
^Frames have been offset for clarity in the figure.

The camera system works concurrently with a GPS/IMU (Global Positioning System/Inertial Measurement Unit) system which records the position and orientation of the camera at each frame. This allows the imagery to be geo-referenced with minimal processing.

2.3 Study area, ground support and field validation

A study site within the Falls Creek Ski Resort in Victoria, Australia was selected and stratified into ten areas based on accessibility during the snow season, vegetation type and type of snow cover (artificial, natural, groomed, non-groomed).

Two independent height datasets were created to verify the performance of the photogrammetrically generated DEM products.

Initially, terrain points were observed on the natural surface using a GPS RTK (i.e. with no snow cover). Each of the ten areas had approximately thirty-five terrain points recorded, yielding ~350 observations.

A second GPS RTK dataset was recorded on the snow surface synchronously with the image capture. This was a sub-sample of the no-snow dataset, where only odd terrain point numbers were observed, although in some areas of steep gradient all sample points were re-observed. This 'half-sample' scheme was adopted due to time constraints, equipment and personnel limitations and the need to complete the survey on the day of image capture. As the snow pack changes rapidly, these point observations had to coincide with the flight period to ensure there was no temporal variation between the validation data and the photogrammetrically derived DEMs. A total of 183 RTK points were observed.

To enhance the accuracy of the photogrammetric data, ground control points (targets) were placed and coordinated. In addition, a local GPS base station was setup to synchronously record data, over a known point during image capture. During the acquisition, a ground support team placed the targets on the snow and observed their position using a GPS rapid-static technique. An RTK observation at each target was also taken as an independent check. Four ground control targets were placed at the corners of the study area. This procedure enabled the photography to be accurately geo-referenced.

The aero-triangulation undertaken by the imagery suppliers gave good results. Differences between stereo-viewed points and GPS target points are shown in table 2.

Point ID	X Diff	Y Diff	Z Diff
cp-01	-0.02	0.02	0.01
cp-02	0.02	0.00	0.00
cp-03	0.04	0.02	-0.08
cp-04	0.02	0.02	-0.20

Table 2: Aero-triangulation results supplied with imagery.

A close inspection of 'cp-04' on the photography found that the point was partially obscured by surrounding vegetation, causing shadowing. This may have affected the ability to place the stereo-cursor in the correct location, therefore causing the larger Z Diff value. The RMS values of the aero-triangulation were 0.03, 0.02, and 0.11, in X, Y and Z, respectively.

These results were supplied along with an EO (Exterior Orientation) file. The EO file (unaltered) was used to orient the images for each stereo model. The EO data consisted of X, Y and Z, and omega, phi and kappa values for each image at time of capture.

2.4 Image Analysis

Image analysis of the digital photography using histogram distributions found that not all 4096 available values were being utilised. Instead, only an average of 3350 data values (82%) was being used for each of the 3 bands, over the ten photographs. Each of the bands had a similar dynamic range. A study by Weichelt et al. (2005) found in digital imagery captured by a DMC, that only about 30%-60% (depending on the band) of available values was used by 99% of the pixels. Weichelt et al. (2005) also comment that even though all 4096 values are not utilised, there are still five to ten times more values than an 8-bit (256 grey values) system.

2.5 Approach

To create the DEM, each set of photography, containing two runs and 5 photographs per run, were treated separately. Specifically models were set up as 60% overlap models, yielding a total of sixteen models.

The 80% overlap was intended for use in a multi-image matching DEM creation, although this was not possible with the version of software available at the time. The 80% overlap photography was not used for stereo matching because of the impact on height determination of the poor base/height ratio when compared to the 60% overlap photography.

To create the DEMs, Integrapp's Photogrammetric software was used, in particular Image Station Automatic Elevations (ISAE). The ISAE software creates collection boundaries that abut each other, therefore preventing overlapping grid points being created. The automated image matching algorithms were used to create surfaces. ISAE creates a surface using two sets of parameters, one for the matching process and the other for the surface interpolation. The result is a grid of points, with an associated X, Y and elevation.

The first set of variables are the image matching and surface reconstruction parameters. The parameters experimented with include a correlation coefficient threshold, colour band, terrain type and adaptive parallax. Image matching is based on a single band, therefore the band with the greatest dynamic range is best suited for this task. Histogram analysis of each image and band found no significant difference between bands. Terrain type and adaptive parallax narrow or widen search spaces between image pairs to find homologous points, for example mountainous terrain would have a larger parallax value than flat terrain. The correlation coefficient threshold is the value set as a measure of similarity of homologous points. Matched points must have a correlation value higher than the threshold. Higher threshold values result in fewer matches, although the points matched are more reliable. Lower values will result in more matches, but with less reliability.

ISAE outputs a regular grid of points which are influenced by the parameters of the match points outlined above, and by a second set of output surface parameters. These parameters include grid widths, post spacing and smoothing factor. Smoothing affects the output dataset, after the surface has been

reconstructed via the image matching and correlation software. A high smoothing factor is appropriate for flat terrain, while a medium to low factor is suited to mountainous terrain. This factor is used by ISAE to smooth out the surface created, filtering out local outliers. The grid spacing and jump interval affect the denseness or sparseness of the output points.

ISAE outputs point-based files, with an associated attribute, base on the matching process. The three categories are ‘grid point’ (matched point satisfying parameters), ‘grid points with low redundancy’ (output points that had a low number of matches) and ‘grid points beyond height accuracy threshold’ (output points that exceeded the nominated height accuracy).

2.6 DEM creations

Only a single set of the captured photography was used, since the base/height ratio was higher and multi-image matching was not used. All models for the set of photography were used when experimenting with parameters. The grid spacing, jump interval and terrain type were constant values set over the attempts (apart from attempt_1), the values were 2 (metres), 1 and ‘Hilly’, respectively. These three values were based on the terrain and the fact that, although in an alpine area, the gradient of the study area is not large and that a 2 metre grid would represent the surface sufficiently.

In the first attempt, the DEM derived from the points created by the automated image matching software had good comparisons with ground GPS data, but the differences exceeded the desired accuracies. The majority of DEMs values were higher than the ground observations. The largest difference was 0.41 m.

From attempt_2, the inclusion of elevation points (point features with an X, Y and Z value), namely the ground observed GPS points, and digitised features improved the DEM moderately. The smoothing was set to low (factor of 1). The same trend occurred in this attempt, in that the majority of DEM values were higher than the ground observations. This attempt became the ‘base’ set of parameters. Variations in parameters occurred one at a time from these ‘base’ values.

Table 3 shows the variables outlined previously for each attempt.

Attempt	Band Colour	Smoothing	Correlation Threshold
1	Red	Medium (2.0)	0.80
2 (Base)	Red	Low (1.0)	0.80
3	Blue	Low (1.0)	0.80
4	Green	Low (1.0)	0.80
5	Red	User-defined (0.5)	0.80
6	Red	Low (1.0)	0.75
7	Red	Low (1.0)	0.80 (Adaptive Parallax)

Table 3: Automatic image matching parameters, for various attempts.

Based on the number of grid points in each category, there was no significant variation between attempts except for attempt_6, which was expected. The number of grid points and points beyond accuracy threshold was 2% more than those of attempt_2, low redundancy points decreased by 4%.

2.7 Manual stereoscopic readings

Manual stereoscopic readings were taken to check for gross errors in the model setups and therefore ensure any inaccuracies or differences in DEM creations were due to the image matching algorithms and parameter changes.

To do this, an experienced photogrammetrist viewed each model stereoscopically. Locations on the imagery where GPS points were collected at the time of image capture were stereoscopically viewed and elevations recorded. More specifically each photo control target that appeared on a model had a manual reading recorded. Most readings compared well to GPS observations. Each RTK observed point (183 in total) was viewed and recorded at least twice, as many of the RTK points appeared on more than one model.

The photo control targets, viewed stereoscopically over the different models, gave similar results to those given by the imagery suppliers. More specifically, ‘cp-04’ had a significantly larger Z difference value than the other targets

Stereoscopic viewings of photo control targets on different days gave mixed results. Although most target readings were within ±0.1 of each other, a few varied by as much as ±0.2. Stereoscopic readings of RTK GPS positions compared well, with ground observations. The standard deviation of differences was 0.10 m.

3. RESULTS AND DISCUSSION

Comparisons between GPS ground observations and DEM creations were reasonable, although the project was aiming for an accuracy better than that which was achieved (thus far). Variations of particular DEM parameters show no significant difference in output accuracy.

Basic statistics were calculated on the differences (GPS observed – DEM value), based on the 183 GPS observations across the study area, and are shown in Table 4. The average maximum difference was -0.37 m, between GPS observations and DEM creations. Average mean was -0.14 m, and the standard deviation 0.08 m. Furthermore, the correlation of differences between attempts was about R² = 0.90.

Buyuksalih et al. (2005) also found the trend of derived DEMs to be higher than ground measurements. In their study they used two DEMs to illustrate this systematic shift, the reference DEM they used corresponded to the terrain and was assessed using ground control points observed with GPS.

Attempt	Min.	Max.	Mean difference	Std. Dev.
1	-0.41	0.04	-0.17	0.08
2	-0.37	0.04	-0.14	0.08
3	-0.35	0.04	-0.14	0.08
4	-0.36	0.05	-0.14	0.08
5	-0.34	0.04	-0.14	0.08
6	-0.36	0.01	-0.14	0.08
7	-0.41	0.01	-0.15	0.08

Table 4: Basic statistics of differences between GPS observations and DEM creations, in metres.

Close investigation of the location of points with large differences found that they were common to areas, in particular areas on the north side of the study area. This may be the adverse affect of 'cp-04'. Further investigation is required for localised large differences.

4. CONCLUSIONS

The shift from analogue to digital camera systems, has opened up many new applications, as well as enhancing and improving current image-based applications. It has always been difficult to create accurate DEMs of snow covered environments due to the spatial and spectral limitations that have hindered automatic image matching techniques in the past. Improvements in spatial and spectral resolutions have increased the accuracy of DEMs created from snow covered, mountainous terrain.

DEMs created in this project have correlated very well to ground-base observations, in particular with a GPS RTK and rapid-static. The largest difference between the DEM and GPS observations was -0.41 m, from *attempt_7*. Differences between GPS observations and DEM values were mostly in the negative direction. That is, the DEM was higher than the ground observations.

High resolution spatial and spectral imagery are ideal in applications of snow or low-textures land cover types. Initial results seem promising.

FURTHER WORK

Investigate the use of 80% overlap stereo-models to create DEMs via the use of multi-stereo matching methods. Incorporate manual stereoscopic measurements into the automated image matching process.

The other aspect of this project is to use spectral reflectance measurements of snow to determine grain size. The overall aim of the project is to obtain characteristics of snow derived from spectroscopy and couple this with snow depth derived from DEMs to determine snow water content or snow water equivalence (SWE) of a snow pack.

REFERENCES

- Bacher, U., Bludovsky, S., Dorrer, E. and Münzer, U., 1999. Precision Aerial Survey of Vatnajökull, Iceland by Digital Photogrammetry, 3rd Turkish-German Joint Geodetic Days, Istanbul.
- Buyuksalih, G., Kocak, G., Topan, H., Oruc, M. and Marangoz, A., 2005. Spot Revisited: Accuracy Assessment, Dem Generation and Validation from Stereo SPOT 5 HRG Images, *The Photogrammetric Record*, 20(110): 130-146.
- Dörstel, C., 2003. DMC - Practical Experiences and Photogrammetric System Performance. In: Fritsch, D. (Ed.), *Photogrammetric Week 2003*, Wichmann, Heidelberg, pp. 161-172.
- Hinz, A., Dörstel, C. and Heier, H., 2001. DMC - The Digital Sensor Technology of Z/I-Imaging. In: Fritsch D. & Spiller R. (Eds), *Photogrammetric week 2001*, Wichmann, Heidelberg, pp. 93-103.
- Leberl, F.W. and Szabo, J., 2005. Novel Totally Digital Photogrammetry Workflow, *Semana Geomatica*, Presentation, Bogota, Colombia.
- Ledwith, M. and Lundén, B., 2001. Digital Photogrammetry for Air-Photo-Based Construction of a Digital Elevation Model over Snow-covered Areas - Blåmannsisen, Norway. *Norwegian Journal of Geography*, 55: 257-273.
- Weichelt, H., Wagner, B. and Klaedtke, H.-G., 2005. Remote Sensing Approach for Digital Aerial Imagery, *ISPRS Hannover Workshop 2005*, Hannover, Germany.
- Wolf, P.R. and Dewitt, B.A., 2000. *Elements of Photogrammetry with Application in GIS*. McGraw Hill.

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