CLOSE-RANGE PHOTOGRAMMETRY AS A TOOL IN GLACIER CHANGE DETECTION

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KEY WORDS: Photogrammetry, close range, terrestrial, change detection, glaciology

ABSTRACT:

The shape and texture of ice surface can give us valuable information about processes affecting glaciers. This presentation introduces a procedure for making close-up digital elevation models (DEM) of glacier surface and the benefits of using these DEMs in glaciological change detection. They can be used to follow accurately the changes of different surface features like melt water channels, glacier tables, ablation hollows etc. The DEMs have been produced using digital photogrammetric methods. To keep the amount of ground control points reasonable concentric images have been connected to panoramic wide-angle images. Experimental research has been carried out using two study sites situated on Engabreen in the West Svartisen in Norway and on Hintereisferner in Austria. Test areas have been small, only 10 x 10 m. Tacheometer and GPS have been used for ground control measurements. The photography has been recorded once a year during a period of three years. DEMs have been constructed using commercial photogrammetric workstation and are very detailed with 20 –50 cm point density. Results indicate that close-up DEMs can be used to densify more sparse DEMs and to detect chances in ice structure and movements.

1. INTRODUCTION

1.1 Motivation

Digital close-range photogrammetry can be used for detailed modelling and visualisation. From instrumental point of view it is a light and cost-effective method for measurements and visualisation of small objects or areas. Panoramic photography gives the advantages of a wide angle image, such as a possibility to get close to an object and to decrease number of control points (Haggrén et al. 2001.) In this study we wanted to find out if panoramic images can be used for photogrammetric DTM measurements and visualisation of temporal change in object.

1.2 Overview

Terrestrial photography has traditionally been used for detecting the position of the glacier snout. In some cases the whole glacier has been tried to cover. There are extensive series of photographs of some areas, especially the Alps, starting from the late 1800's. More recently aerial and satellite images have mostly replaced this type of photography. (Finsterwalder 1954, Gao and Liu 2001). However, there are still applications where terrestrial photography is adequate (Theakstone 1997). The high accuracy of the DEMs makes it possible to detect small details on the glacier surface. Covering of large areas is, however, quite laborious, but for a change detection in a limited area close-up views offer a very useful technique. The reformation of the glacier surface can be followed by repeating the photography at the same place with a suitable time frequency. In this study the photography was repeated three times during a three years period.

Changing weather conditions make the glacier surface a subject to many processes effecting its shape and structure. The amount of supraglacial debris has also a major influence on the surface topography. As a matter of fact the whole glacier surface is full of features starting from large crevasses down to tiny holes and mounds. Melting and refreezing of ice are common phenomena during the summer causing together with glacier movement a numerous amount of surface features that form and reform throughout the melting season. Some of these features can stay several years but many of them will last only days or even hours. (Benn and Evans 1998: 228-230, Betterton 2001). As the photography was repeated three times on two completely different environments, it gives a good chance to get an overall idea what the surface changes are alike.

The glacier test sites are located on Engabreen in West Svartisen in Norway and on Hintereisferner in Austria. The test areas are small, only 10 x10 m. The photography was repeated three times during a period of three years. The ground control points were measured with a tacheometer. On Engabreen the camera was standing on solid rock in front of the glacier edge, giving the possibility to use same camera places and ground control points throughout the study. As it was not safe to go on the ice, all the control points are in front of the glacier. On Hintereisferner it was not possible to photograph or make tacheometer measurements from the sides of the glacier because of the loose gravel and masses of rolling stones. Therefore all the camera places and control points were located on ice.

The lens distortions were corrected and single images were combined to panoramic images. Panoramic stereo pairs were oriented using digital stereo workstation. The DEMs were measured from absolutely oriented stereo models.

2. MODEL CONSTRUCTION

2.1 Panoramic Images

All terrestrial photography was recorded with an Olympus Camedia C-1400L digital camera. The size of a single record is 1280 x 1024 pixels. The wide end of the zoom optics was used, corresponding to a focal length of 1400 pixels. The camera has been calibrated and lens distortions of images have been corrected.

Panoramic images have to remain concentric while rotating the camera in order to preserve the central projection. The concentricity is controlled with a cross slide on the camera stand. In this study panoramic sequences consisted of three images with an overlap of approximately 30 %. This corresponds to an approximate angle of view of 120° (Figure 1). In plane projection a panoramic image with a wider angle of view than 180° grows infinitively large. The images were combined using two dimensional projective transformation. The algorithm has been presented by Pöntinen, 2000.

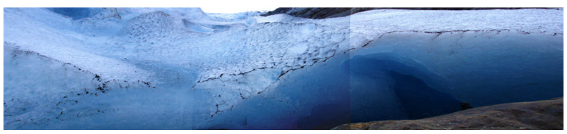

Figure 1. A panoramic image combined from a sequence of three images.

2.2 Orientations

The orientations of panoramic images were calculated using Intergraphs Z/I digital workstation software. The geometry of ground control points complicated the absolute orientations of the Engabreen stereo models. The control points were located in front of the view, causing errors to the more distant areas of the models. In the year 2002, one control point was measured on the glacier surface. As expected, that improved the results.

On Hintereisferner the control points were located on ice. The geometry of the control is good but there is a possibility that the control points had moved between the photography and the tacheometer measurements, because it was not possible to record the photography simultaneously with tacheometer measurements.

2.3 Digital Elevation Models

The digital elevation models were digitised from the absolutely oriented stereo models using Intergraphs Z/I software. In Engabreen DEMs (Figures 2 and 3) the point density is 20 cm while it is 50 cm in Hintereisferner DEMs.

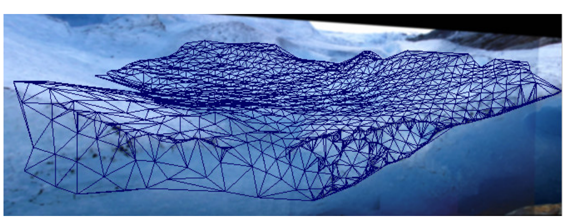

Figure 2. DEM of Engabreen test area in 2001

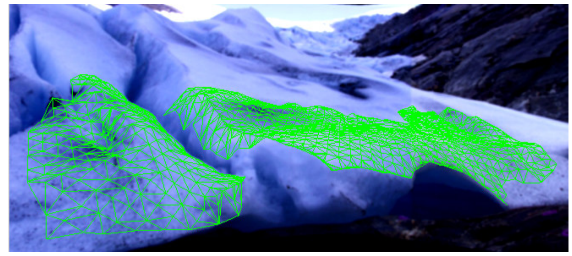

Figure 3. DEM of Engabreen test area in 2002

2.4 Densification of Smaller-Scale DEMs

Close-range DEMs can also be used to densify air-borne DEMs. The points of a sparse model can be projected to a terrestrial stereo model in order to visualize differences or to estimate the accuracy of the air-borne DEM. The terretrial DEM of Hintereisferner test area in 2002 is presented in Figure 4 and part of an air-borne laser scanner model projected on it in Figure 5. Stereo viewing shows that the models don't match correctly, but it also shows that there are some false points in the laser data.

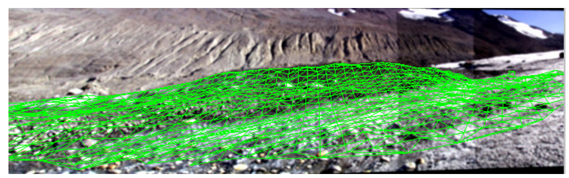

Figure 4. The terrestrial DEM of Hintereisferner test field in September 2002.

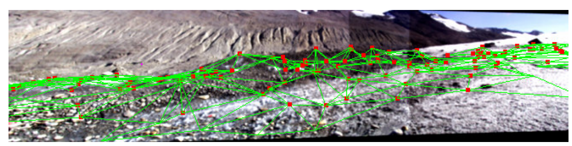

Figure 5. The laser DEM of the Hintereisferner test field (processed by Olli Jokinen) from the same day as the terretrial DEM.

2.5 Glaciological Change Detection

On the Engabreen study area the glacier surface is highly crevassed as the glacier tongue is flowing down on a steep slope. Quite a lot of melt water is available, but the melt water channels do not form a stable network because of the rapid ice movement. Despite that the effects of the melt water can be significant target in DEMs. There are almost no supraglacial debris at all. Occasionally some ablation hollows occur surrounded with a very thin dirt layer. As the hollows are more exposed to the sun on one side than another their location tend to change. The movement can be as much as a few centimetres in one day requiring an extensive study period. (Ferguson 1992: 36-38, Betterton 2001).

On Hintereisferner there are lots of debris on the glacier surface close to the glacier sides and snout. The supraglacial debris absorbs more sunlight than clean ice, which affects strongly to the melting of the ice. A thin debris layer (less than a few cm) will transfer the heat to the ice beneath and increase melting. On the other hand a thicker layer will insulate the ice and reduce melting. Large stones and boulders are also protecting the ice from melting. These so called glacier tables can finally be well above the glacier surface supported by an ice pile. Dirty cones and ridges are features consisting mostly of ice but are covered with a debris layer. Their development depends on the particle size and thickness as well as the slope angle. (Østrem 1959: 228, Drewry 1972, Kajuutti 1989, Kirkbride 1995: 289-291, Benn and Evans 1998: 228-230, Betterton 2001). The change of different debris covered features is a suitable target to be followed with close-up photography.

3. RESULTS AND DISCUSSION

The orientations of terrestrial stereo image pairs are affected by the weaknesses in quality of images, in the accuracy of measurements, and in the quality of ground control. In the case of panoramic images also poor stability of projection centre during photography distorts DEMs. Therefore the camera must be set up very carefully as the glacial terrain is often rough and unstable.

The importance of reliable ground control is emphasized in case an object is moving during the series of repeated photography. The DEMs of successive years have to be matched for the comparison and change detection. On Engabreen the possibility to measure the ground control to a solid rock has most likely improved the results of absolute orientation. On the other hand on Hintereisferner the net of control points has been regular as it was possible to measure it on the glacier itself. For a better matching the DEMs should be wider covering some solid land, which could work out as a reference. On Engabreen this would be fairly easy to carry out. On Hintereisferner it is almost impossible because of the loose sediments around the glacier tongue.

3.1 Relative Orientation

The accuracy of relative orientation depends highly on the geometry of panoramic images. In case the projection centre of an image sequence has not been stationary, the geometry of the central image is still correct but the adjacent images are distorted. This will show up in relative orientation as grown residuals of points of that area. In normal case the whole panoramic image cannot be used for DEM measurements as the pixels near both ends of a panoramic image tend to stretch when rectified to a plane. Standard errors of unit weights (Z/I Imaging, 2001) of stereo models vary between 0.3 to 0.8 pixels. It corresponds to 9.6 to 25 µm. Table 1 shows the y-parallaxes of one panoramic stereo model.

Engabreen 2002

Pt ID	PY(px)	Arc seconds (")
101	0.19	28.07
102	0.01	1.46
103	0.07	11.70
104	0.21	33.95
105	0.11	17.54
01	0.01	1.79
10	0.06	8.93
11	0.56	91.46
12	0.44	71.97
106	0.59	95.85
107	0.83	135.48
108	0.21	33.30
109	0.06	9.75

Table 1. An example of results of relative orientation. Y-parallaxes after orientation are expressed in pixel and arc second units. Standard error of unit weight is 0.33 px (53.03").

3.2 Absolute and Exterior Orientation

The accuracy of absolute orientation depends mainly on the accuracy of ground control and the accuracy of the relative orientation. If the relative orientation is affected by a displacement(s) of the projection centre during the photography of an image sequence, the absolute orientation will also be corrupted. Tables 2 and 3 show the results of absolute and exterior orientation and the differences to measured coordinates of projection centres of two panoramic stereo pairs. The results show that exterior orientation gives better solution in this case.

Engabreen 2002

Absolute orientation (m, gon)	Left	Right	**AO-measured**(m) Left	Right
X0 (m)	909.302	908.970	-0.352	-0.301
Y0	442.250	442.173	-0.328	-0.353
Z0	247.252	247.260	-0.214	-0.225
Omega	-99.584	-99.590		
Phi	-33.130	-29.952		
Kappa	-199.506	-199.557		
DOF	5			
RMS X	0.049			
Y	0.044			
Z	0.029			

Exterior orientation (m,gon)	Left	Right	**EO- measured**(m) Left	Right
X0 (m)	908.914	908.645	0.036	0.024
Y0	441.905	441.810	0.017	0.010
Z0	247.064	247.060	-0.026	-0.025
Omega	-101.528	-101.502		
Phi	-36.9120	-33.364		
Kappa	199.147	199.219		
DOF	2	2		
RMS X	0.005	0.005		
Y	0.003	0.003		
Z	0.003	0.004		

Tacheometer measured coordinates (m)	Left	Right
X0 (m)	908.950	908.669
Y0	441.922	441.820
Z0	247.038	247.035

Table 2. The results of absolute and exterior orientation of a panoramic stereo pair from Engabreen and the differences to the measured camera places.

Hintereisferner 2002

Absolute Orientation (m, gon)	Left	Right	**AO-measured**(m Left	Right
X0 (m)	724.16	723.835	-1.206	-1.327
Y0	6357.281	6357.206	0.599	0.505
Z0	2595.888	2595.882	-0.21	-0.149
Omega	-103.226	-103.227		
Phi	-19.005	-18.263		
Kappa	197.927	98.458		
DOF	11			
RMS X	0.443			
Y	0.446			
Z	0.444			

Exterior orientation (m,gon)	Left	Right	**EO- measured**(m) Left	Right
X0 (m)	723.457	723.003	-0.503	-0.495
Y0	6358.076	6357.961	-0.196	-0.25
Z0	2596.073	2596.08	-0.395	-0.347
Omega	-101.762	-101.742		
Phi	-20.935	-20.525		
Kappa	199.275	199.769		
DOF	6	6		
RMS X	0.051	0.052		
Y	0.022	0.016		
Z	0.241	0.242		

Tacheometer measured coordinates (m)	Left	Right
X0 (m)	722.954	722.508
Y0	6357.880	6357.711
Z0	2595.678	2595.733

Table 3. The results of absolute and exterior orientation of a panoramic stereo pair from Hintereisferner and the differences to the measured camera places.

4. CONCLUSIONS

The paper presents a method to use terrestrial panorama images to detect changes in glacier surface. Series of concentric images were taken at test fields on Engabreen and Hintereisferner. The camera places were situated similarly to normal case of terrestrial stereo photography. Series of concentric images were combined to panoramic stereo pairs, which were oriented relatively, absolutely and by single images. The relative orientation of images was basically acceptable, excluding the far ends of images, where pixels stretch.

Movements of the projection centre during the photography of an image sequence cause difficulties in relative orientation and distortion to stereo model. In practice the residuals of the side images of a sequence grow. In this study the residuals are smaller after exterior orientation than after absolute orientation. It is assumed to be predominantly a consequence of the errors of relative orientation. The results show that exterior orientation gives best solution in this case. If ground control can be duly realized, the terrestrial photography can be considered as a feasible method for the glacier change detection of small areas.

5. ACKNOLEDGEMENT

The authors are grateful to the European Commission for financial support. The study was done as a part of the OMEGA project (EVK2-CT-2000-00069 in the 5th framework), from which also the laser data was obtained. We also want to thank our Austrian and Norwegian partners for their help during the field work.

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