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GPS-ASSISTED PHOTOGRAMMETRY FOR MAPPING PRODUCTION IN ANTARCTICA

ABSTRACT: MARSELLA M. & VITTUARI L., *Gps-Assisted Photogrammetry for Mapping Production in Antarctica.* (IT ISSN 0391-9838, 1997).

In 1993 an airborne Gps-assisted photogrammetry project was carried out in the Victoria Land region (Antarctica) with the performance of 12 aerial photography missions. Successful application of Gps photogrammetry allows for reduction of the number of ground control points (Gcp). The benefits of airborne Gps in the production of high-accuracy spatially referenced data deserves particular attention when operating in difficult environments, such as polar regions for glacier monitoring or mapping purposes. Gps determined positions of photo centers and control points can be used during the aerotriangulation procedure preliminary to the photogrammetric plotting. A comparison between the digital and analytical aerotriangulation approach is made in the paper. Furthermore an images auto-correlation algorithm was tried out for the automatic production of the ice shelf Digital Terrain Model (Dtm) and relative ortophoto production.

KEY WORDS: Gps, Digital Photogrammetry, Mapping, Glacier Monitoring.

RIASSUNTO: MARSELLA, M. & VITTUARI L., *Fotogrammetria assistita dal Gps per la produzione di cartografia in Antartide.* (IT ISSN 0391-9838, 1997).

Nel 1993 é stato realizzato un progetto di fotogrammetria aerea assistita dal Gps nella Terra Vittoria (Antartide) tramite l'esecuzione di 12 rilievi aerei. L'impiego della fotogrammetria assistita dal Gps permette la riduzione del numero di punti di controllo da stabilire a terra rendendo tale tecnica particolarmente adatta a zone remote o di difficile accesso, quali quelle polari nell'ambito del monitoraggio di ghiacciai o di produzione di cartografia. Le posizioni dei centri di presa e dei punti di controllo determinate tramite il Gps possono essere utilizzate nelle fasi di triangolazione aerea che precedono la restituzione fotogrammetrica. Nel presente lavoro è stato confrontato l'approccio digitale con quello analitico per le fasi di triangolazione aerea. Inoltre è stato sperimentazione un algoritmo di correlazione automatica di immagini in grado di produrre il Modello Digitale del Terreno (Dtm) della piattaforma di ghiaccio e la relativa ortofoto.

TERMINI CHIAVE: Gps, Fotogrammetria *digitale*, Cartografia, Monitoraggio di ghiacciai.

INTRODUCTION

The impact of the Global Positioning System (Gps) technology adopted in support of photogrammetric mapping is both in the convenient establishment of high accuracy ground control and in the determination of camera station positions at the instant of exposure. Gps derived photo centers can be introduced as observations with the image coordinates into «combined» block adjustment reducing the number of required ground control points. Therefore, the benefits of airborne Gps in the production of high-accuracy spatially referenced data deserves particular attention when operating in difficult environments, such as in polar regions, where the establishment of ground control points is extremely onerous because of both logistic and economic requirements.

Unfortunately, the performance of the Gps technique in polar as well as equatorial regions, is not optimal (Seeber, 1993; Vittuari, 1994) and, indeed, the stringent accuracy demands for large scale photogrammetry are hardly satisfied, while the requirements for small scale photogrammetry can be easily met.

In 1993 using the latest satellite-based Gps technology, an airborne Gps controlled photography project was carried out in the Victoria Land region of Antarctica. The main objective of the program was the collection of images over the Convoy Range, Ross Island and Browns Peninsula regions. The project also aimed at demonstrating improved

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efficiency by the integration of Gps technology into aircraft navigation and camera systems. In 12 missions, photographs were obtained at various altitudes in support of small scale mapping and orthophotos ranging in scale from 1:50,000 to 1:5,000. The mapping products, digital and numerical, are essential for Antarctic research and in support of operational and logistical activities; a new application area is the digital photogrammetry technique for rapid production of orthoimages, Digital Terrain Models (Dtm) or Geographical Information System (Gis) databases.

A number of photogrammetric strips was flown over areas of special interest (protected and managed areas, glaciers, etc.) and in support of a project for glaciology. Among these, two photo strips were taken over the Hells Gate Ice Shelf near Terra Nova Bay (Victoria Land, Antarctica).

The Hells Gate Ice Shelf is a small ice platform of about 70 km^2 located near the Italian Base of Terra Nova Bay. The extreme meteorological conditions acting on a limited area make this ice shelf an interesting site for collecting data and modelling ice body changes studying dynamic and structural processes (Souchez & *alii,* 1991; Tison & *alii,* 1993). Many geophysical and geodetic surveys have been carried out in the area in order to monitor sea tidal undulations, ice shelf surface changes and to detect the grounding line. Starting in 1993 static, fast static and kinematic Gps measurements have been repeated over the area thus allowing for the establishment of a number of precisely determined Gps reference points (Capra & *alii,* 1996).

Selected results from analytical and digital image processing of aerial photographies controlled with Gps taken in 1993 over the Ice Shelf are shown in this paper.

GPS-ASSISTED PHOTOGRAMMETRY

In order to perform an airborne Gps photogrammetry project the aircraft has to be equipped in the conventional manner for acquiring aerial mapping photography but has to be modified with the installation of a flight qualified Gps antenna. As shown in fig. 1, the configuration planned for the Antarctic flights consisted of one antenna mounted on the top of the fuselage, aft of the cabin and over the camera system, and of a second antenna positioned forward over the cabin. This dual system is designed to collect redundant Gps data to be used as control for the kinematic positioning. The aerial camera provides a pulse at the midpoint of the exposure and the shutter time is recorded in order to interpolate the number of pulse (generally one or two) per second corresponding to the Gps observation. The components of the antenna-camera offset vector is accurately measured in the aircraft system (axis parallel to the longitudinal and lateral axes of the aircraft and in the vertical).

The standard procedure required for the integration of Gps and photo measurements to obtain mapping products is summarized in fig. 2. The first stage consists in processing separately the collected images, on one hand, and the raw Gps observable, on the other. Image processing can be done using an analytical or digital stereoplotter to perform interior orientation and measurements of image coordinates. The analytical approach is lengthier than the digital one which is extremely rapid but demanding in terms of hardware and software requirements; furthermore digital processing requires images in digital form either directly acquired or rasterized using high resolution photogrammetric scanners.

The actual integration of Gps derived aerial and ground control points with the reduced photo measurements is achieved by performing a combined aerial triangulation bundle adjustments to derive adjusted threedimensional coordinates and orientation parameters. It should be noted, though, that the camera orientation parameters include not only coordinates of the position of photo center (directly derived by interpolation of the Gps kinematic solution) but also the image orientation angles. Moreover, with the exclusion of some small scale applications, the observed Gps coordinates should be reduced to the actual positions of perspective centers. Depending on the approach adopted, the camera stations and ground control points, as well as the adjusted coordinates have to undergo different coordinate transformation before and after the adjustment: a possible approach designed for mapping application is also shown in fig. 2 (Colomina, 1993).

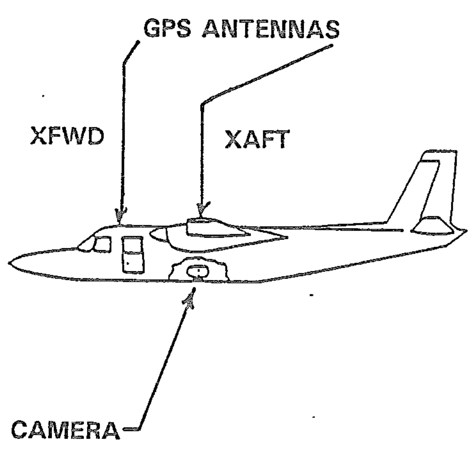


FIG. 1 - Gps antennas configuration on the aircraft.

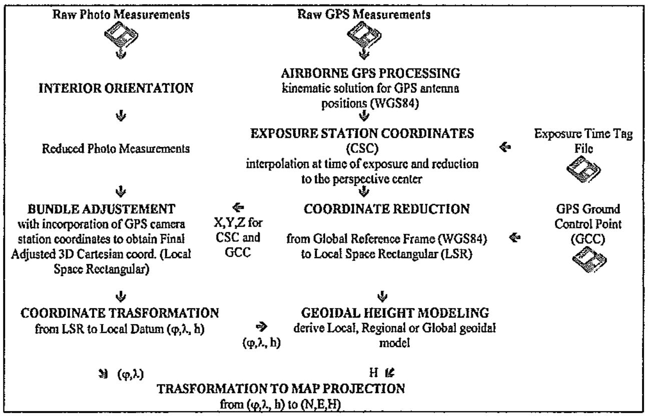


FIG. 2 - Procedure for integration of Gps data into Aerial Triangulation adjustment.

The accuracy required for each photo center depends on the map-scale specifications. In tab. 1 the approximate geo-spatial reference accuracy required from airborne Gps, defined within the Antarctica mapping and orthophoto program are listed. The basis for the estimation of the allowable error for each horizontal component (at 1-sigma level) is about 1/3 of the distance on ground represented by 0.25 mm of the intended scale for map or orthophoto.

TABLE 1 - Mapping accuracy requirements

Scale	ground distance (m)	σ (m)
1:250,000	± 72.50	< 20
1:100,000	± 25.00	< 8
1:50,000	± 12.50	< 4
1:25,000	± 6.25	< 2
1:10,000	± 2.50	< 0.8
1:5,000	± 1.25	<0.4
1:3,000	± 0.75	< 0.25

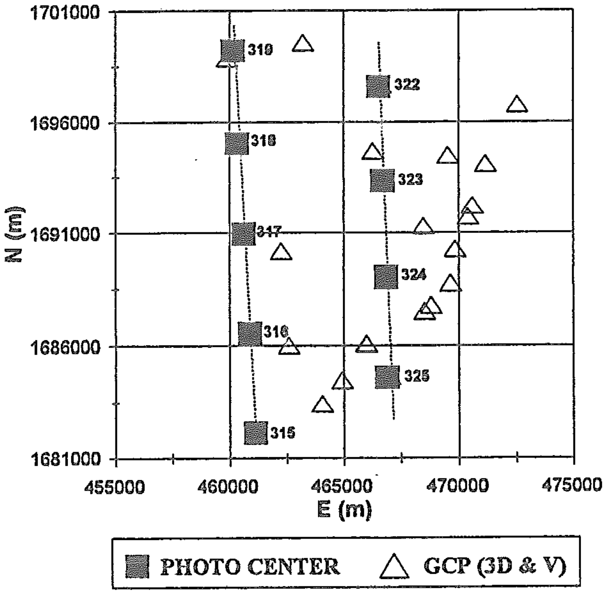


FIG. 3 - Positions of Gcp and photo centers.

THE HELLS GATE GPS-PHOTOGRAMMETRY PROJECT

During the 1993 Antarctic aerial photography program, the Pnra-Enea arranged for photographs to be taken over areas of interest for the Italian research units.

The aircraft equipped with Gps receivers flew two 7-photo strips at a nominal photo scale of 1:45,000 over the Hells Gate area. In tab. 2 the main characteristics of the project are listed; in fig. 3, indicated by the sequence of the camera centers, the two photo strips and the location of Ground Control Points (Gcp) are shown. A number of photoidentifiable tridimensional Gcp were selected and surveyed using reference stations of the Italian geodetic network.

TABLE 2 - Main characteristics of the project

THE HELLS GATE PROJECT	
InitialClient	Enea
Day	23 Nov. 93
Area Location	163 45 E, 74 59 S
Line kilometers	50 km
Total Land Area	550 km^2
Forward Overlap	60 %
Side Overlap	30 %
Flying Height	25,000 ft
Aircraft	Rockwell Turbo Commander 690 B
Aircraft operations	2 receiver/antennas
GPS Receiver	Ashtech P12/Trimble SSE
Reference stations	MCM1, MCM2 TNBO
Camera model	Zeiss RMK A 15/23
Focal length	152,871 +/– 0.005 mm
Photo Scale	1:45,000
Strips0/Photos	2/14
3D GCP	8

AIRBORNE GPS DATA PROCESSING

In order to have high accuracy Gps positions, differential processing of Gps carrier phase signals is required. This implies the use of a reference station on the ground observing at the same time as the aircraft Gps systems. Since the accuracy of the positioning depends on the distance from the reference station, an additional receiver (besides to the two sites established at Mc Murdo) was operational in the vicinity of the project area at Terra Nova Bay. Gps observations were collected at a sampling rate of 1 second and adopting a «cutoff angle» of 10 degree for the satellite elevation over the horizon., thus allowing for the visibility of a high number of satellites (between 8 and 11). Anti-Spoofing (As) was off during the missions and all observations from dual frequency full wavelength P-code receivers were available.

Redundant data were collected using a two receiver/antenna (Fwd and Aft) configuration mounted on the aircraft which made it possible to obtain two independent solutions for the aircraft positions; thus the length of the vector established between the two aircraft antennas was computed at each epoch and compared with a reference value obtained from an a-priori Gps static survey of higher accuracy. The difference between the known baseline length (Fwd-Aft) and that derived from the processing relative to one reference station can be used to detect blunders and determine internal consistency of the kinematic solutions. Systematic errors or common errors in both antennas can be detected only if more than one reference station on the ground is available. Methods for validation of kinematic data through use of redundant data, both on the ground and on the aircraft, are widely described in recent literature (Cannon & *alii*, 1994, Marsella, 1996).

The Gps data processing was performed using the Pnav software (Ashtech, 1992) which provides ionosphere-free float solutions using both available Gps signals L_1 and L_2. As a comparison the software Geotracer (Terrasat, 1994) was also used to compute iono-free solutions. Both softwares have On-The-Fly (Otf) capability, which allows for initializing the processing after signal interruptions, and use smoothing filter algorithms. Using Pnav the positions for the two antennas Aft and Fwd were computed relative to the two Ashtech receivers located at the McMurdo Base Station, namely MCM1 and MCM2. The capability of Geotracer in processing mixed receivers data allows for the use of the Trimble 4000 SSE receiver located at Terra Nova Bay (Tnbo) as reference station for Fwd.

DISCUSSION OF RESULTS

Airborne Gps camera Stations

An overall analysis of the results was performed comparing the aircraft trajectory estimated using different reference stations; furthermore, the length of the fixed baseline between the Aft and the Fwd antennas computed epoch by epoch using the kinematic Gps solutions was validated adopting as reference value the length obtained from a more reliable static solution.

The analysis led to the conclusion that the accuracy of the Gps aircraft position, in the presence of high ionospheric disturbance, ranges from 0.5 m for the horizontal components to the 1-2 m for the vertical components. The comparison of the Pnav and Geotracer solutions (fig. 4) for the Fwd antenna resulted in a systematic difference of about 1.5 m in the vertical component during strip 2. These systematic differences can be addressed to problems deriving from the different approaches of the Otf algorithms in presence of signals characterized by high noise level. The use of Otf procedure is required in order to recover the integer values of carrier phase ambiguities after discontinuities of Gps signals generally occurring during aircraft turns.

Due to a large gap in the observations from MCM1 occurring in correspondence of all the exposures of the first strip and to the higher noise level from the Aft antenna, the solution MCM2-Fwd can be considered to be included in Aerial Triangulation adjustments.

As already mentioned, high accuracy kinematic Gps positioning is not easy in critical areas, as Antarctica, where the Gps carrier phase signal shows large discontinuities due to the high noise level induced by ionospheric short term variations. To deal with this situation the processing algorithm should be able to recover and, eventually, re-initialized the signal acquisition many times during a survey. Since the performance of Otf algorithm is considerably worsened by the presence of noisy observations, the results obtained from the kinematic processing cannot in any case reach the same level of accuracy usually achieved in a less problematic environment.

In order to improve the quality of Gps derived camera centers, special processing approaches have to be adopted for Antarctic data (Vittuari, 1994). Optimal procedures are still under investigation and at this stage of the experiment the Gps camera centers are not yet included in the subsequent analysis.

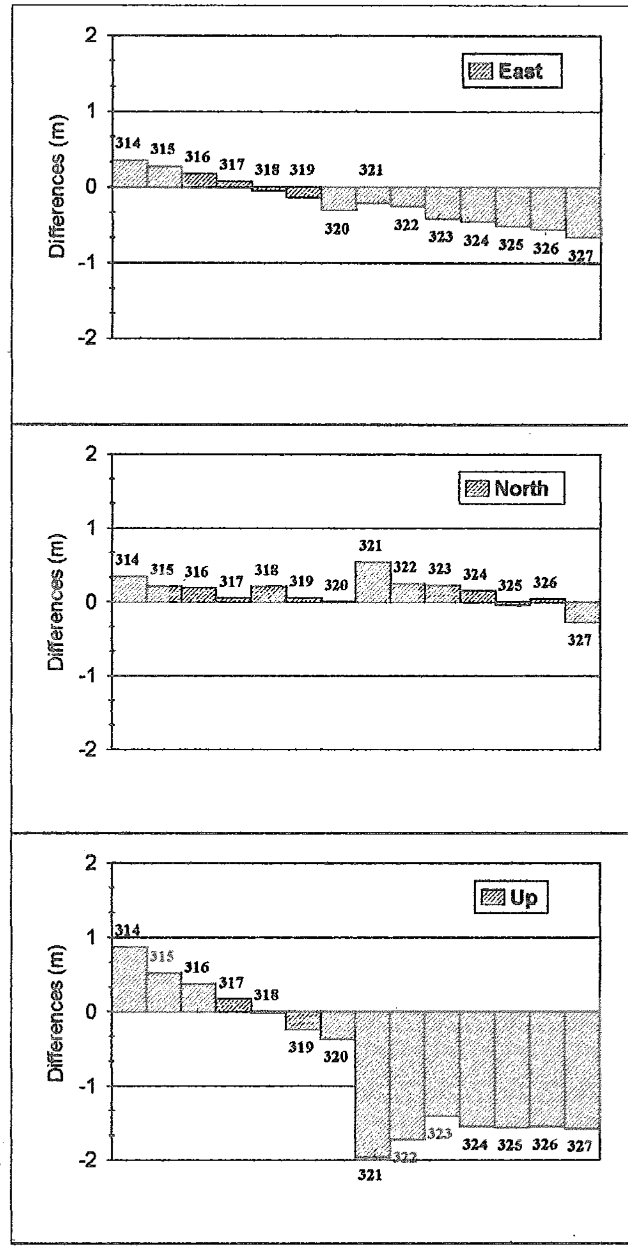


FIG. 4 - Comparison between Pnav and Geotracer solution for camera center position.

The Aerial Triangulation Adjustments

Gps post-processing and network adjustment led to an accuracy for the Gcp positioning at decimeter level but, as described in the following, the same level of accuracy could not be maintained due to the process of photo iden-

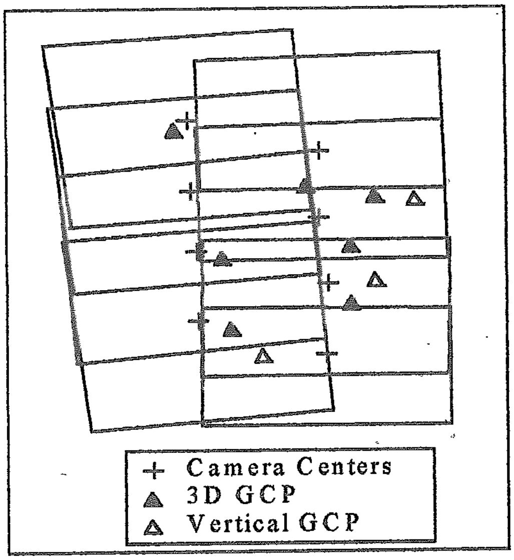


FIG. 5 - Photogrammetric block processed with the Helava workstation.

tification of the Gcp. The accuracy of photo-identified points is highly dependent on image scale and on the experience of the operator and the process is even more critical in the case of non panelled points before flight. In the Hells Gate area, due to the frequent presence of extreme windy conditions and in order to avoid environmental impact with a permanent marker, it was decided not to panel Gcp. Thus, the points were located on well delimited rocks with dimensions suitable for photo identification and the approximate locations were indicated on slides from different views. In such conditions the process of photo-identification can be considered valid within 1-2 m only.

In fig. 5, the photos selected to be processed are shown. The photogrammetric processing was performed using the analytical stereoplotter, Digicart 40, with a nominal measurement resolution of 1-5 µm, and the Digital Photogrammetric Workstation Leica-Helava DPW770. During the measuring stage a number of additional vertical control points were added in both cases before proceeding with the AT adjustments and derive the parameters of exterior orientation.

It should be noted that using a digital stereoplotter a sub-pixel accuracy can be reached and this means that the quality of mensuration of image coordinates depends on the scanning resolution. In this experiment, the scanning was performed at 1000 dpi (dot per inch) which corresponds to a pixel dimension of 25 mm at the image scale.

The Helava internal Aerial Triangulation procedure (Hats) was used and performed a bundle adjustment. Gps derived control points were pointed on the screen while an automatic procedure allows for locating and measuring control tie point coordinates in the images.

In tab. 3 results from the two Aerial Triangulation adjustments are shown in the form of standard deviations of residuals on Gps ground control and of tie points.

Gps kinematic results are to be optimized using alternative processing approaches, the Gps camera stations can be introduced as a known parameter into the Aerial Triangulation adjustments in order to reinforce the solution.

TABLE 3 - Results from Aerial Triangulation solution

	DIGICART			HELAVA		
SI		2/8			2/8	
No of Tie Pt		27			25	
No. of 3 DGCP		8			7	
No. of VCP		12			3	
GCP ms (m)	133	1.15	0.99	0.73	1.67	1.02
Tie Pt. ms (m)	0.62	0.48	0.47	0.35	0.89	0.67

DIGITAL ORTHOPHOTO PRODUCTION

An orthophoto is a digital image obtained by processing an aerial photography in order to remove all the distortion due to the camera obliquity, terrain relief and features (fig. 6).

The digital image is rectified in an orthographic projection by means of the processing of each image pixel based on the photogrammetric equations derived from the ground control points, the camera parameters and the Digital Terrain Model (Dtm). Thus each pixel is corrected for the effects of the relief and the inclination of the camera. The final product is a spatially accurate image with planimetric elements expressed in their corrected coordinates, in other words combining the characteristics of photography with those of a «potential» map. It is clear that to

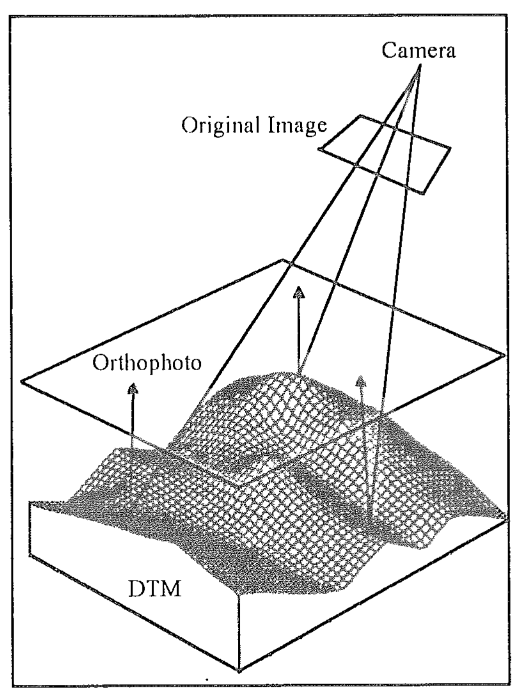


FIG. 6 - Scheme of orthophoto generation.

reach the quality of a mapping product the orthophoto has to be submitted to further processing stages, such as interpretation, classification and generalization.

The production of digital orthophotos is considerably preferrable in the case of applications which require coverage of large areas in a short time (i.e. production and revision of digital mapping series) or high time resolution monitoring (natural hazard, planning, environmental resource managing and evaluation, etc.). Due to its flexibility for the production of derived products and for combination with other sources of data, a digital orthophoto can be adopted as a base for any Gis system which accepts raster images. Orthophotos can be used for inventory, change detection and monitoring in environmental management, geology, engineering planning and agriculture.

In order to produce an orthophoto starting from images in digital form, coordinates of photoidentifiable ground control points, calibration and attitude parameters of the camera and a digital elevation model (Dem) are also required. In the last few years software for the generation of digital orthophotos has been developed and implemented in complex systems of different capabilities, named Digital Photogrammetry Workstation (Dpw) (Heipke, 1995). These systems make use of methods for differential rectification and process digital data now available from many sources of satellite remote sensing and aerial digital photography.

Furthermore, using Gps receivers the acquisition of ground control points necessary to perform the aerotriangulation procedure and, if required, to derive the calibration parameters of the image sensor has became fast, precise and economic. By means of these recently developed Dpws the production of an orthophoto allows for a fast and accurate collection and merging of data to be used in many disciplines.

The entire procedure for the production of an orthophoto can be summarized in the following main steps:

1. scanning of the aerial photographs (if not taken directly in digital form) using a photogrammetric scanner device at a resolution function of the scale and quality of the photography;
2. viewing of the raster images using the Dpws interactive stereo plotting capability (the most sophisticated systems usually reach subpixel accuracy);
3. performing an aerotriangulation procedure to derive the parameters of exterior orientation of each image by measuring control and tie point coordinates in multiple images; an interesting feature of Dpws is the capability of performing automatic processes for point transfer (measuring of image coordinates of a point in one image with given coordinates in another image);
4. automatic (large-scale imagery) or semi-automatic (small-scale imagery) extraction of a Dtm from the stereo imagery; this is usually followed by an interactive procedure of Dtm verification and editing which allows for accessing and improving the accuracy level;
5. geometric image transformation, for example to generate digital orthoprojection;
6. connecting multiple images on the border (mosaicking), map generation;
7. raster plotting.

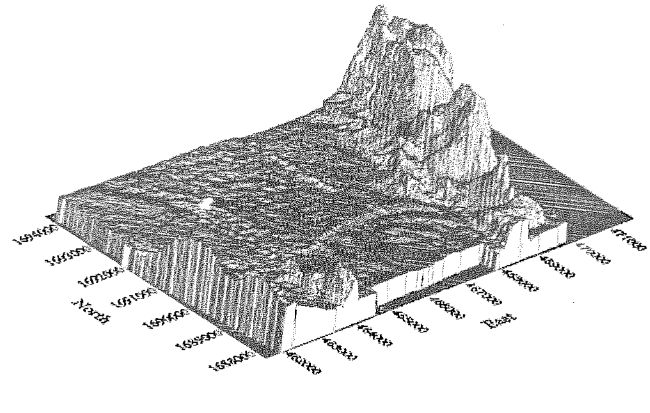


FIG. 7 - Dtm derived from Helava digital system.

One of the most complete Dpw systems available on the market is the Leica-Helava Dpw series (Miller, 1992) which, among other features, offers aerotriangulation and Dtm generation capabilities. The system is completed by a high resolution photogrammetric scanner. The Leica-Helava system was used for the production of an orthophoto of a part of the Hells Gate ice shelf.

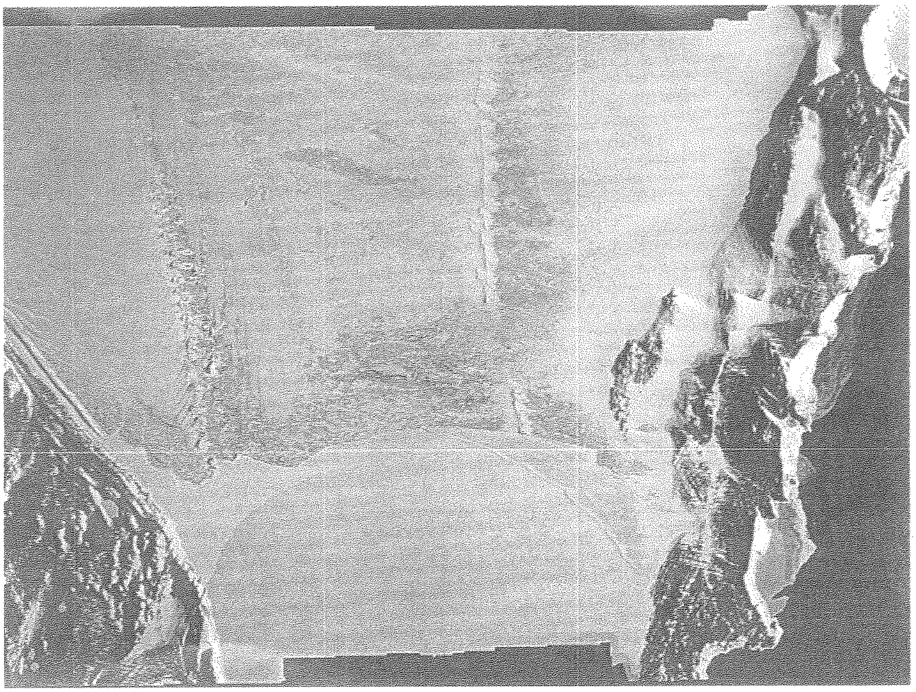
THE HELLS GATE ORTHOPHOTO GENERATION

Two images were selected from the two 5-photo strips (fig. 5) for the ortophoto generation. Using an automatic batch process, the Dtm was extracted from the stereo imagery; manual interaction allows for selecting a different interpolation strategy to accomplish the different morphology (flat and steep terrain) and for a smooth editing in critical areas. A perspective view of Digital Terrain Model computed by the Leica-Helava system is shown in fig. 7. By overlapping the Dtm to the orthorectified image, the digital orthoprojection was carried out (fig. 8). Contour lines derived from the Dtm can be overlayed on the orthophoto and with the addition of legends, grid lines, topographic information and title block a graphically completed othophoto map can be drawn automatically.

CONCLUSIONS

The 1993 aerial photography campaign is the first example of use of the fixed-wing airborne Gps project in support of control for aerial photography in Antarctica. The airborne Gps accuracy for the derived camera station coordinates appeared to be within acceptable limits in consideration of the map-scale requirements but need to be carefully validated before incorporation in AT adjustment. The use of Digital Photogrammetry Workstations made it possible to perform a rapid image processing for the generation of Dtm and orthoimages, two products which can be adequately used to extract 3D information in the framework of studies of surface changes.

FIG. 8 - Orthophoto generated from Helava digital system.



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