EXPERIENCES WITH THE HELAVA AUTOMATED TRIANGULATION SYSTEM

Thomas Kersten, William O'Sullivan
swissair Photo+Surveys Ltd.
Dorfstr. 53, CH - 8105 Regensdorf-Watt, Switzerland
Phone +41 1 871 22 22, Fax +41 1 871 22 00
e-mail: [thomas.kersten, willi.osullivan]@srpv.ch

Commission III, Working Group 1

KEY WORDS: Aerial, digital, GPS, triangulation, bundle block adjustment

ABSTRACT

In this paper, we present our investigations and results on a digital aerial triangulation of two Swiss test blocks using the Helava Automated Triangulation System (HATS). In a pilot study, digital image data scanned with a resolution of 25 µm, from the block St. Gallen/Appenzell including 106 b/w images and from block Zug (82 b/w images), both at a photo scale of ca. 1: 27'000, were triangulated. The measurements were carried out on the Helava/Leica Digital Photogrammetric Workstation DPW770 each using a different tie point pattern. All observations were later adjusted in the GPS supported bundle adjustment program BLUH using self-calibration. The empirical accuracy from check points, which had not a very good quality due to their various sources, was better than 1 m in planimetry and in height using GPS photo centre coordinates and sparse ground control information in the combined adjustment. The RMS values of the GPS station coordinates were about 0.6 m in planimetry and 0.2 m in height.

1. INTRODUCTION

With the development of higher-resolution scanners, high quality digital imagery is increasingly available. Additionally, with the progress in high performance computer hardware and software, e.g. higher-resolution screens and faster image-handling capabilities, automation of photogrammetric processes becomes presently possible. Image processing and computer vision techniques have successfully been employed for facilitating automated procedures in digital aerial images such as interior orientation (Schickler, 1995; Lue, 1995; Kersten and Häring, 1995), relative orientation (Schenk et al., 1990), point transfer in photogrammetric block triangulation (Tsingas, 1992), and the generation of Digital Terrain Models (Krzystek, 1991).

The first digital photogrammetric system has been commercially available on the market since 1987. Today, with each new release, systems provide an increasing degree of automation in implemented photogrammetric procedures. In the past five years these systems are increasingly used in photogrammetric production to significantly improve the efficiency of the production processes. Specially in aerial triangulation, digital photogrammetric stations are surpassing conventional analytical plotters in accuracy and functionality, i.e. in the degree of automation in data capture and processing. Currently several commercial digital photogrammetric systems, e.g. Intergraph ImageStation, Leica DVP, DiAP from ISM, Helava/Leica DPW670 and DPW770 among others are available for photogrammetric production. To produce digital orthophotos for the entire area of Switzerland, swissair Photo+Surveys Ltd. purchased digital photogrammetric equipment from Helava/Leica. For the project SWISSPHOTO blocks including in total 7800 colour resp. infrared photos must be processed within the next couple of years to meet the requirements of many customers in providing digital orthophotos as up-to-date basic data for various GIS applications. Consequentely this requires a high level of automation in all production processes, e.g. scanning, aerial triangulation, DTM and orthophoto generation, mosaicing, data management, etc., for efficiency, time and cost saving reasons.

In this paper we present our investigations and results of a digital Aerial Triangulation (AT) of two blocks using the Helava Automated Triangulation System (HATS). The goal of a pilot study was to test the performance and the functionality of HATS. The object was to provide sufficient ground control to perform a traditional AT and compare the results with a GPS supported AT using GPS coordinates of the photo centres with a minimum amount of ground control points. Results of the GPS supported bundle adjustment and experiences with the functionality of HATS are presented. The advantages and disadvantages of HATS for automated digital triangulation under production conditions are also discussed in this paper.

2. TEST DATA AND PHOTOGRAMMETRIC SYSTEMS USED

2.1. Test data

Two test blocks were selected comprising of ca. 2% of the large block covering the entire area of Switzerland. For the project SWISSPHOTO (Kersten and O'Sullivan, 1996), Switzerland was flown in two phases using colour and infra-red films simultaneously. In phase 1, the urban areas and the northern part was flown from June to August, while in phase 2 the Alps and all valleys in the southern part were flown from August until October 1995.

The photo scale was approximately between 1: 24'000 and 1: 28'000 in the non-mountainous areas including the separate flights in the southern valleys and between 1: 34'000 and 1: 45'000 in the alps. During the flights camera stations were recorded by DGPS using a Leica GPS receiver in the airplane and at each of three reference stations on the ground. Additionally, 104 well distributed points of the new Swiss GPS primary network LV'95 were signalized as control points. Flight and block data are summarized in Table 1.

For this pilot study 106 images (St. Gallen) resp. 82 images (Zug) at a scale of about 1:27'000 spread over 5 (6) parallel flight lines for each block were selected covering the major part of the Cantons of St. Gallen and Appenzell in the north-eastern region of Switzerland and the whole Canton Zug. The flight lines were flown from east to west and in the opposite direction with an azimuth of ~20 resp. 200 degrees. The dates and times of the flight lines varied from the 30.06.95 to 20.07.95 and from 7.25 AM to 12.44 PM (UTC).

2.2. Hardware

The aerial triangulation was performed on a Helava/Leica digital photogrammetric workstation DPW770. All images were scanned on a Helava/Leica Digital Scanning Workstation DSW200 in RGB mode. The turn around time for scanning for each photo was about 30 min. For triangulation the digitized colour images were converted into greyscale images in order to reduce disc space usage. The resolution of the images was 25 μm (1016 dpi), which corresponds to a footprint of approximately 0.7 m on the ground, and the size of each greyscale image was about 80 MByte. Large portions of the approximately 75 GByte available disc storage capacity were used for the triangulation data.

2.3. Software

For the test block St. Gallen the software release SOCET 3.1.6b (beta version) was used, while the test block Zug was measured with the latest SOCET 3.1.1.2. version. HATS is a fully digital system for performing block triangulation of suitably overlapping images. The tedious process of selecting and measuring image coordinates of pass and tie points is highly automated, with the possibility of operator override. The system flags unacceptable tie points and

	Block 1	Block 2
Area:	St. Gallen, Appenzell	Zug
Area covered:	~1000 km^2	670 km^2
Ground height:	400 - 1700 m	400 - 1900 m
Flying height a. s. l.:	~ 4800 m	~ 4800 m
Camera:	Wild RC30, 15/4 UAGA-F	Wild RC30, 15/4 UAGA-F
Photo scale:	~1: 27000	~1: 27000
Forward/side overlap:	70%/30%	70%/30%
Number of strips:	5	6
Number of images:	106	82
Date of flight:	30.6.95/20.7.95	30.6.95/20.7.95
Film/digital imagery:	colour diapositive/greyscale	

Table 1: Flight and block data of the test blocks St. Gallen and Zug

displays the required images for measurement, and the operator remeasures these unacceptable points by moving the floating mark to their proper location

3. DIGITAL AERIAL TRIANGULATION

The triangulation was divided into several processing steps, which included the preparation, measurements and the final bundle adjustment.

3.1. Preparation

Before starting the measurements, the image import and the minification of the images (building-up image pyramids) was performed in a batch mode. The GPS photo centre coordinates of each image were also imported to provide approximate values for the overlapping of the images in the blocks. In the block St. Gallen (Zug) only 4 (2) signalized LV'95 points were available. Their distribution was not ideal, but the points were visible. To obtain sufficient ground control points without establishing an additional GPS campaign four different sources were used for this pilot study:

- signalized points from the new Swiss GPS primary network LV'95
- 3-D control points from previous photogrammetric in-house projects measured on the SD2000
- planimetric control points from cadastre maps at 1:500 - 1:2,000 scale
- height control from LK25 maps (Swiss 1: 25'000 map series)

The preparation of the ground control was a very time consuming effort. In total, for block St. Gallen 54 h and for block Zug 42 h were used.

3.2. AT measurements

The processes of AT measurements in HATS are divided into several steps which includes Automatic Points Measurements (APM), Interactive Point Measurements (IPM), and Blunder Detection and Simultaneous Solve (Re-measurements).

Before starting HATS the Interior Orientation must be performed. For the interior orientation the first two fiducial marks were measured in a semi-automatic mode, while the rest of the eight fiducials were measured fully automatically. A fully operational automatic interior orientation for the DPW770 is introduced by Kersten and Häring (1995), which can be performed in batch mode without any operator's intervention. Before running APM a tie point pattern was selected and edited to obtain a well distributed point configuration in each image for connecting the block. The tie point pattern consisted of 16 points for block St. Gallen. For block Zug the standard 3x3 tie point pattern was used. After APM 75% of all points were measured successfully for block St. Gallen, while in total 266 points required an interactive measurement. For APM block Zug was divided into two subblocks, where in the first subblock 78% and in the second subblock 71% were measured successfully, while in total 70 resp. 142 points required an interactive measurement. Blunder detection could be used after each measurement mode and gross errors were eliminated. The blunder detection was a very useful tool for „online" checking of model and strip connections as all 106 (82) images could be displayed, and all connections re-checked and re-observed if necessary.

Ground control points and additional points were measured with IPM. If the datum is fixed by measurement of three control points, the program drives the operator to the approximate position of the subsequent ground control points automatically. The correct identification of natural points was not as easy as using an analytical instrument, and using points on houses for example was found not to be a good idea due to problems from height differences for the correlation algorithm. If natural points are to be used, we propose that only points on relatively flat surfaces be used in the future. The AT observations were adjusted using HATS and the resulting RMS was 0.34 pixel, X=0.6 m, Y=0.5 m and Z=1.5 m for block St. Gallen and 0.35 pixel, X=0.5 m, Y=0.5 m and Z=0.3 m for block Zug.

3.3. Bundle adjustment

All observations (image coordinates, control point coordinates and GPS photo centres) were adjusted in a combined bundle adjustment with self-calibration for each block separately. For this GPS supported bundle adjustment the data was adjusted at the University of Hannover using program BLUH. As a reference the results of an adjustment without using the GPS station coordinates (see table 2) were compared to results of a GPS supported adjustment (see table 3) in order to see the accuracy potential of GPS supported aerial triangulation for SWISSPHOTO data. For the adjustment without GPS 39 (36) horizontal and 47 (47) vertical control points were used for block St. Gallen (Zug). In the combined bundle adjustment only 4 horizontal and 11 resp. 16 vertical control points were used, while as a measure of accuracy all other control points were used as check points (see table 3).

For the St. Gallen and Zug data the root mean square values of differences at control points is about 0.6 resp. 0.4 m in planimetry and about 0.7 resp. 0.4 m in height (see table 2). Theoretically is should be possible to obtain at least a precision of 1/3 of a pixel,

block	Control H/V	obs	red	σ_0 [μm]	RMS X [m]	RMS Y [m]	RMS Z [m]
St. Gallen	39/47	3201	1105	11.1	0.60	0.60	0.68
Zug	36/47	2239	785	9.9	0.35	0.33	0.40

Table 2: Bundle adjustments without GPS

block	adj	Control H/V	Check H/V	σ_0 [μm]	RMS X_0 [m]	RMS Y_0 [m]	RMS Z_0 [m]	μ_X [m]	μ_Y [m]	μ_Z [m]
St. Gallen	GPS	4/11	39/47	11.1	0.59	0.57	0.13	0.93	0.81	0.96
Zug	GPS	4/16	36/47	11.4	0.57	0.44	0.18	0.72	0.72	0.96

Table 3: Combined adjustments

which corresponds to 8.5 μm and 0.25 m in planimetry and 0.5 m in height at a photo scale of 1: 27'000. Thus, compared to what is achivable the RMS values in table 2 are slightly worse. Also, there were slight differences of the results compared to the adjustments with HATS (see above) which could be attributed to different weighting of control points.

In the combined adjustment 12 resp. 5 station coordinates observations from the St. Gallen resp. Zug block were eliminated from the adjustment due to gross errors. The RMS value of the GPS photo centres are about 0.6 m in X_0 and Y_0, and better than 0.2 m in height. When using all control points as check points the combined adjustment yields an empirical accuracy (μ_{XYZ}) which is by a factor 1.5-2 worse than the RMS values from the reference adjustment.

These results show that the quality of the ground control points is not very good. Specially, many of the ground control points taken from the cadastre maps were not of sufficient quality as well as the fact that the cadastre was partially out of date. Here, correct weighting of control points was very important for the adjustments. This demonstrates clearly that it is necessary to perform the GPS supported triangulation using only signalized points, GPS photo centres and additional height control at overlapping strip ends. Thus, further subblocks which are to be processed of block Switzerland must be defined in an area of at least four available signalized control points. To test the quality of height points in LK25 maps, 83 well distributed points were measured in the block St. Gallen, which were triangulated with HATS, and used as height check points. As a result the average difference of all points was 1.4 m, which is slightly worse than the μ_Z = 0.96 m from the comparison of the control points used as check points, with the maximum difference being 4.1 m.

3.4. Time required

The following time was required to process the in table 4 summarized AT processing steps.
The total elapsed time which was required excluding scanning, ground control preparation and data transfer for triangulation of block St. Gallen was 51 h. This corresponds to 28 min per image. Benefitting from the experiences of the first triangulation block all 82 images of block Zug were processed in 27 h, which corresponds to 20 min per image resp. 24 images per day (8 h). Taking only the measurement time into account, we were able to triangulate 32 images of block Zug in one shift. In comparison the large differences in the time used for blunder detection and manual measurement of ground control as indicated in table 4 can be attributed to the better knowledge of the user interfaces and to the improved interface of version 3.1.1.2 while processing the second block. But the reduced elapsed time for block Zug compared to block St. Gallen must also be partially attributed to the use of a sparse tie point pattern, which causes less interactive point measurements. Compared to conventional triangulation on analytical plotters this is only a slight speed-up, but, in general, there is still potential for improvements in digital triangulation using HATS. In table 4 all lines in *italics* indicates processes, which could be automated or where the elapsed time could be reduced significantly from our point of view.

No	AT processing step	mode	St. Gallen	Zug
1	*Preparation for AT (data files)*	*manual*	2.0 h	4.0 h
2	*Interior Orientation*	*manual*	2.0 h	2.0 h
3	Automatic Point Measurement	batch	2.3 h	1.3 h
4	Interactive Point Measurement	manual	10 h	5.0 h
5	Blunder Detect & Solve	manual	15 h	2.0 h
6	*Measurement of ground control points*	*manual*	8.0 h	2.0 h
7	*Simultaneous Solve and Re-measurements*	*manual*	8.0 h	7.0 h
8	Final GPS supported block adjustment	manual	3.0 h	3.0 h
		Total	50.3 h	26.3 h

Table 4: Processing steps for AT and elapsed time

4. ASSESSMENT OF HATS

The quality of the results and the efficiency of the whole triangulation process are dependent on the algorithm used for the measurements. In our investigations the following aspects caused problems for the correlation algorithm:

- Extreme height differences in the images resp. block
- Strips with different flight dates (vegetation changes in summer)
- Shadows from early morning flights (bad quality terrain representation)
- Densily forested areas and lakes

To improve HATS with respect to speed, precision, robustness and user friendliness we suggest the following software improvements which are summarized below:
(1) The superimposition of the tie point pattern in any image/model of the whole block with the possibility of interactive placement of tie points in anticipation of problem areas which will occur in APM will improve the success rate of measured points.
(2) The use of an existing DTM in APM speeds up the APM process and increases the robustness significantely, so that less IPM will be required afterwards. We have in Switzerland for example a hectare-raster DTM covering the whole country, which could be used.
(3) The use of GPS camera station data in HATS should be supported more efficiently.
(4) An ideal improvement of increasing speed after APM would be to measure the tie points only in their two nadir images across strip direction and the program then is capable of measuring all other related combinations of this point automatically.
(5) The implementation of an image matching technique (Gruen, 1985), which uses besides two shift parameters also two shears and scales, improves the precision of the measurements slightly. A small drawback of a slightly reduced speed should be neglected.

Comparing the latest HATS with an earlier version of the orientation tool in SOCET Set it must be stated that the graphical user interface and the additional implementated options increased the userfriendliness significantly. In Kersten and Stallmann (1995) the SOCET Set version 2.4 was compared to an experimental software package and no significant differences were found between both software packages. Both systems used a semi-automatic measurement mode, but the image matching algorithm in the experimental system performed 10% more accuratly than the correlation algorithm of SOCET Set. Today, the system from Helava provides much more automation in data processing and the advantages of HATS are:

- Automatic measurement mode using an user defined tie point pattern
- Quasi online blunder detection for eliminating gross errors
- Point remeasurement capability after residual checking

As a drawback of the overall system it must be noted that the build-up of a graphical user interface or the redisplay of images on the extraction monitor is often too slow (up to 20 seconds during the measurement mode). In general, the zoom capability should be improved as well.

5. CONCLUSIONS AND OUTLOOK

Digital aerial triangulation was performed with two test blocks, St. Gallen and Zug, using HATS. It was found, that HATS including the highly automated measurement procedure is a powerful triangulation tool, which can be recommended for use in production. To increase the efficiency of the digital triangulation, HATS has still potential for improvements as mentioned above. During processing the AT using beta version of HATS 3.1. problems occured, which could be solved in coorperation with experts from Helava. In experience, it can be summarized that for such a complex and highly tuned software package like HATS extensive training and well documented user manuals are absolutely necessary to be capable of driving through problem situations with the software.

The achived results of better than 1m in planimetry and in height is not satisfactorily using images with a photo scale of 1: 27'000. But we have to be aware that the ground control resp. check points were not of a very good quality, which influences the results significantly. Although the results are approximately the same using different tie point patterns, we recommemend the use of the dense tie point pattern for more reliable connecting of the block. AT using the conventional amount of ground control is time consuming and requires a lot of resources. Using only the minimum ground control of 4 points with additional height control and the GPS photo centre coordinates can speed up and automate the process significantly. Thus, the goal for using the recorded GPS photo centre coordinates is to avoid time consuming efforts for providing sufficient control points from various resources in a optimal configuration and distribution, and in sufficient accuracies.

However, we think, that we can reduce the time needed and the manual intervention of the operator significantly for GPS supported aerial triangulation in the future to produce much more efficiently. We hope that we can triangulate more than 40 images per shift using HATS in the near future.

6. ACKNOWLEDGEMENTS

The investigations for this paper were supported by the SWISSPHOTO team, by the very good cooperation with Helava Associates Incorporated (San Diego), and by some bundle adjustment computations of Dr. K. Jacobsen (University of Hannover). Their support is gratefully acknowledged.

REFERENCES:

GRUEN, A., 1985. Adaptive Least Squares Correlation: A Powerful Image Matching technique. *Southafrican Journal of Photogrammetry, Remote Sensing and Cartograhy 14 (3),* pp. 175-187.

KERSTEN, Th., HAERING, S., 1995. Automatic Interior Orientation for Digital Aerial Images. *Internal Report, Institute of Geodesy and Photogrammetry, ETH Zurich.*

KERSTEN, Th., STALLMANN, D., 1995. Experiences with Semi-automatic Aerotriangulation on Digital Photogrammetric Stations. Digital Photogrammetry and Remote Sensing '95, St. Petersburg, Russia, *SPIE Vol. 2646,* pp. 77-88.

KERSTEN, Th., O'SULLIVAN, W., 1996. Project SWISSPHOTO - Digital Orthophotos for the entire area of Switzerland. *International Archives of Photogrammetry and Remote Sensing,* Vienna, Austria, July 9-19, Vol. XXXI, Part B2.

KRZYSTEK, P., 1991. Fully Automatic Measurement of Digital Elevation Models with MATCH-T. *Proceedings of 43rd Photogrammetric Week,* Vol. 15, Stuttgart University, Sept. 9-14, pp. 203-214

LUE, Y., 1995. Fully Operational Automatic Interior Orientation. *Conf. on Geoinformatics '95,* Hongkong, May 26-28.

SCHENK, T., TOTH, C., LI, J-C., 1990. Zur automatischen Orientierung von digitalen Bildpaaren. *ZPF - Zeitschrift für Photogrammetrie und Fernerkundung,* No. 6/90, pp. 182-189.

SCHICKLER, W., 1995. Ein operationelles Verfahren zur automatischen inneren Orientierung von Luftbildern. *ZPF - Zeitschrift für Photogrammetrie und Fernerkundung,* No. 3/95, pp. 115-122.

TSINGAS, V., 1992. Automatisierung der Punktübertragung in der Aerotriangulation durch mehrfache digitale Zuordnung. *Ph. D. dissertation, DGK Reihe C Heft 392,* München, 110 S.