Results of digital aerial triangulation using different software packages

Thomas Kersten
Swissphoto Vermessung AG
Dorfstr. 53, CH - 8105 Regensdorf-Watt, Switzerland
Phone +41 1 871 22 22, Fax +41 1 871 22 00
e-mail: thomas.kersten@swissphoto.ch
http: //www.swissphoto.ch/

ABSTRACT

Commercial software packages for digital aerial triangulation are on the market since the middle nineties. The point transfer capability of the current major triangulation software packages was investigated in the OEEPE/ISPRS test on the performance of automatic point transfer in digital aerial triangulation. In this paper, results of digital aerial triangulation using the three major triangulation software packages Helava Automated Triangulation System (HATS), Match-AT and Phodis-AT are presented. For the comparison of the results of the adjustment and the elapsed time for triangulation, the Swiss triangulation block Wittenbach was used. The results of the triangulation, which were obtained from the three digital systems and an analytical plotter, were similar. But, the elapsed time for triangulation using the different systems varied. Finally, differences of the two software packages HATS and Match-AT are discussed with respect to their functionality and performance.

1. INTRODUCTION

Digital aerial triangulation is increasingly being carried out in photogrammetric production environments as greater efficiency is being aimed for through increased automation. Currently, the major digital aerial triangulation (AT) software packages on the market are the Helava Automated Triangulation System (HATS) from LH Systems, Match-AT from Inpho and Intergraph, and Phodis-AT from Zeiss. Furthermore, other vendors as Autometric, Vexcel (IDAS), and KLT provide software for digital AT since some years. Recently, new software for digital AT has become available from Erdas (IMAGINE OrthoBASE), VirtuoZo and DVP. The AT software from Erdas is based on algorithmic developments of the University at Hannover, Germany (Jacobsen and Wegmann, 1998; Wang, 1998).

Up to now only two comparison tests have been published to evaluate the functionality and performance of the major triangulation software packages. In the OEEPE/ISPRS test, the performance of tie-point extraction in automatic aerial triangulation of the major available triangulation software packages was tested using the same test material of various small blocks. The results of 21 participants (four major commercial photogrammetric software providers, five national or regional mapping organisations, four private companies, and three research institutes) using experimental software from Universities, HATS, Match-AT (Inpho and Intergraph) and Phodis-AT are summarised in Heipke and Eder (1999). Within an evaluation of digital photogrammetric systems at the Swiss Federal Office of Topography, the triangulation software of all participating vendors was tested. The results of this evaluation were published in Kaeser et al. (1998).

In order to test an alternative triangulation software to HATS in production, Swissphoto Vermessung AG rented Match-AT from Inpho (Stuttgart, Germany) for three months. The software was mainly tested in the digital aerial triangulation of Block Switzerland (Kersten, 1999). For a direct comparison, digital aerial triangulation of block Wittenbach, a small block in the north-eastern part of Switzerland, was performed using HATS and Match-AT. The same data set was also delivered to Zeiss (Oberkochen, Germany) for investigations with Phodis-AT. Furthermore, block Wittenbach was also triangulated at an analytical plotter DSR14 at Swissphoto Vermessung AG.

In section 2 the major automatic triangulation software packages are briefly compared. The test block Wittenbach and the triangulation software used are introduced in sction 3. The results of digital triangulation using three digital systems and one analytical plotter are presented in section 4, while in section 6 HATS and Match-AT are compared in more detail with respect to the Swissphoto production environment.

2. MAJOR SYSTEMS FOR DIGITAL AERIAL TRIANGULATION

The following major digital triangulation software packages are briefly compared in this section:

(1) LH Systems DPW670/770 with HATS on UNIX/NT

(2) ImageStation Z (Intergraph) with MATCH-AT (Inpho) on NT

(3) Phodis (Zeiss) with PHODIS-AT on Silicon Graphics

(4) MATCH-AT (Inpho) on Silicon Graphics

The major triangulation software packages are described by vendors and some users as summarised in Table 1.

AT software	Paper from vendors	Paper from users
HATS (LH Systems)	DeVenecia et al., 1996	Kersten and O'Sullivan 1996, Kersten and Haering 1997b, Kersten et al. 1998, Kersten 1999
Match-AT (Inpho)	Krzystek et al. 1996, Krzystek 1998	Kaeser et al. 1999
Match-AT (Intergraph)		Urset and Maalen-Johansen 1999
Phodis-AT (Zeiss)	Braun et al. 1996	Hartfiel 1997, Masala 1999

Table 1: Technical papers of vendors and users about aerial triangulation software.

Important features	HATS	Match-AT (Intergraph)	Match-AT (Inpho)	Phodis-AT
Interior orientation	automatic	semi-automatic	semi-automatic	automatic
DTM integration	yes	yes	yes	no
GPS integration	initial values	yes	yes	initial values
APM	yes	yes	yes	yes
Algorithm	cross correlat.	FBM/ABM	FBM/ABM	FBM/ABM
IPM	stereo	stereo	mono	mono
Bundle block adjust.	module	integrated	integrated	external

APM Automatic Point Measurement
FBM/ABM Combination of feature and area based least squares matching
IPM Interactive Point Measurement

Table 2: Important features of automatic triangulation software.

In order to achieve a high level of automation in digital triangulation, the following features are important for the triangulation software:

(1) Interior orientation is a simple task, which should be performed fully automatically today.

(2) The integration of an available digital terrain model (DTM) supports the performance of the automatic point transfer significantly, especially in difficult terrain with large height differences.

(3) The integration of GPS data (XYZ co-ordinates of the camera stations) or the use of initial values of the camera stations supports the performance of the automatic point transfer significantly due the sensitivity of the measurement algorithm to initial values.

(4) Automatic point measurement (APM) is the key module of automatic digital aerial triangulation.

(5) The measurement algorithm influences the quality of the measured points. The combination of feature (rough measurement) and area (precise measurement) based least squares matching achieves better precision than cross correlation.

(6) The interactive point measurement (IPM) provides the capability for the operator to measure semi-automatically control points and additional tie points in mono or stereo (3-D) mode.

(7) The integration of the bundle block adjustment increases the automation of the triangulation significantly (e.g. automatic blunder detection and elimination), if easy-to-use and automatic functionality for analysis of the results and quality control is available.

3. TEST BLOCK AND SYSTEMS USED

For the triangulation tests, the Swiss block Wittenbach, which is located in Canton St. Gallen in the north-eastern part of Switzerland (see Fig. 1), was prepared. Four flight lines were flown in April 1998 in north-south resp. in south-north direction with an overlap of 80% in strip direction and 30% in across strip direction. The block represents an agricultural and urban (small villages) area with some forests, while the terrain is hilly with height differences of up to 340m in the block. 16 ground control points were signalised. The distribution of these signalised ground control point in the block is illustrated in Figure 2 (see points with error vectors). For triangulation, all images with an overlap of 60% in strip direction were used, but in some areas of lines 2 and 3 additional images with an overlap of 80% were

	Block specifications
Flight date	April 20th, 1998
Camera/Lens	Leica RC30, 15 cm
Photo scale	~ 1: 8'000
Overlap (F/S)	80%/30%
Strips/images	4/48
Height range	480 - 820 m
Terrain characteristics	agriculture, forests, urban
Scanner	LH Systems DSW300
Scan pixel size	12.5 µm

Table 3: Flight and block data of the triangulation test block Wittenbach.

integrated in the line (see in Fig. 2), to test the software for changes of overlap within the strips. The flight and block data of block Wittenbach is summarised in Table 3.

In total, 34 colour images of the block Wittenbach were scanned at a Digital Scanning Workstation DSW300 of LH Systems in RGB mode TIFF format. The turnaround time for scanning each photo was about 15 minutes using a SUN Ultra 1. The scan pixel size of the images was 12.5 µm. For triangulation, the digitised colour images were converted into greyscale images in order to reduce disk space usage. The file size of each greyscale image was about 330 Mbyte. For Match-AT and Phodis-AT, all images were available in TIFF, while for HATS the images were converted into VITEC format.

The aerial triangulation test was performed on both a digital photogrammetric workstation DPW670 (SUN Ultra 2) of LH Systems using HATS and a Silicon Graphics (SGI O2, R5000) using Match-AT. For HATS, software release 4.0.10.2 of SOCET SET (Softcopy Exploitation Tools) was used, while for Match-AT release 2.0. The analytical triangulation of 35 images was performed at the analytical plotter Kern DSR14 using the software ORIMA-T. The triangulation with each of the aforementioned systems was performed at Swissphoto Vermessung AG in Regensdorf-Watt. Additionally, block Wittenbach was triangulated at Zeiss in Oberkochen using Phodis-AT (Release 2.0.1).

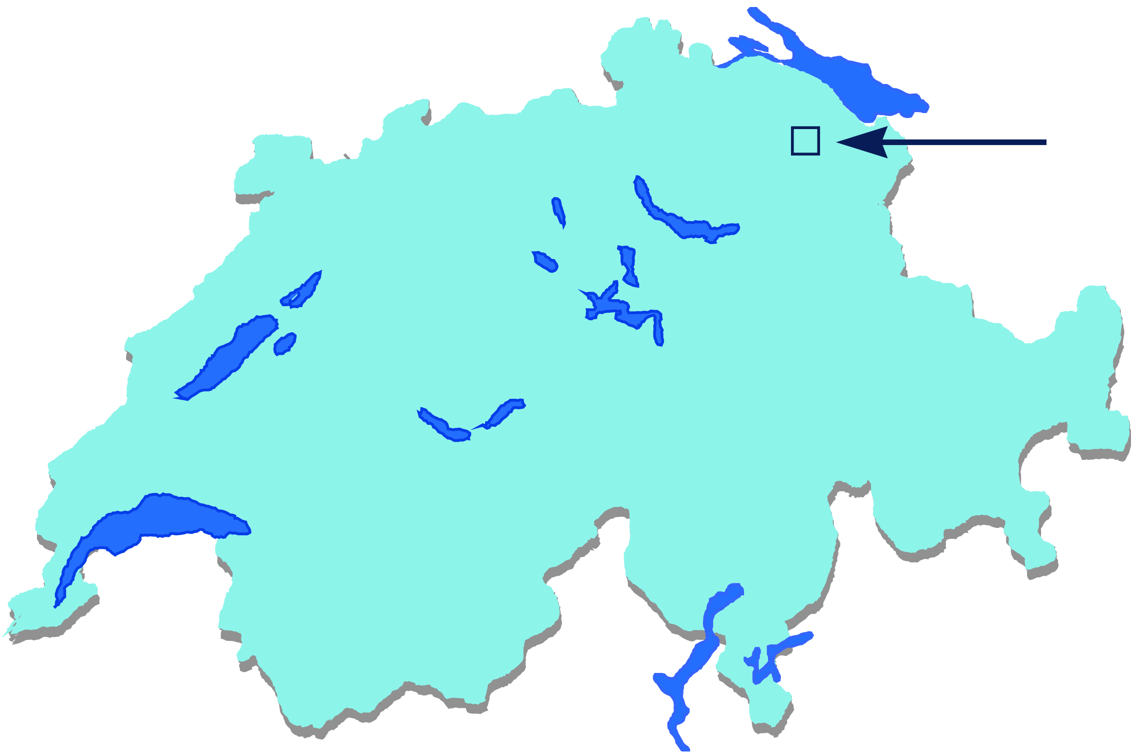

Figure 1: Location of triangulation test block Wittenbach (Switzerland).

4. DIGITAL AERIAL TRIANGULATION AND RESULTS

In the following, the triangulation of block Wittenbach is briefly described for each system. For all systems used at Swissphoto, the following information resp. data were available before the start of the triangulation: (a) colour contact copies of the photos, (b) analogue images, (c) digital images , (d) overview of the flight lines, (e) overview of the ground control point locations in a 1: 25'000 map, (f) sketches of each ground control point, and (g) initial values of each camera station determined from the 1: 25'000 map. For triangulation with Phodis-AT, the information/data c, d, e, and g were send to Zeiss. For all digital systems, the triangulation was performed without a digital terrain model as terrain approximation and without compression of the images.

4.1. Analytical triangulation with the Kern DSR14 using ORIMA-T

The workflow of analytical triangulation with the Kern DSR14 using ORIMA-T is summarised in the following:

(1) Preparation

- Marking of control points on the contact copies
- Input of camera and ground control point data

(2) Measurements with ORIMA

- Input of stereo model (colour diapositives) on the stage of the analytical plotter
- Interior orientation
- Measurement of ground control points
- Measurement of tie points in the „von Gruber" locations including marking of their measured positions on the contact copies
- On-line adjustment of each measured model for quality control in strip direction

(3) Adjustment and quality control

- Data transfer (image and ground control co-ordinates) to the external adjustment software
- Bundle block adjustment using BLUH (University of Hannover) including blunder elimination and quality control
- Update of the orientation elements at the analytical plotter

The analytical plotter DSR14 has an estimated precision of 5-8 microns. A complete quasi on-line adjustment of the whole block is also possible using the full version ORIMA-T, which was not available at Swissphoto. In total, three gross errors were eliminated in the bundle block adjustment. Furthermore, one full control point was reduced to a vertical control point due to false measurements for this point.

4.2. Digital triangulation with HATS

The customised and modified workflow of digital triangulation using HATS is described in Kersten and Haering (1997b) in detail. To facilitate the use of the highly automated AT processing modules by the operator, some additional software for batch processing and easy-to-use graphical user interfaces (GUIs) were developed by Swissphoto Vermessung AG. The AT workflow was performed as follows:

(1) Preparation

- File preparation (camera, orientation parameter of camera stations, control points)
- Image data import including initial values of the orientation elements and image pyramid generation
- Automatic interior orientation including quality control (Kersten and Haering, 1997a)
- Definition of AT parameters including definition of a dense tie point pattern (98 points per image)
- Visual check of image/strip overlap (quality control of initial values of exterior orientations)

(2) AT measurements

- Semi-automatic or interactive point measurement (IPM) of ground control points
- Automatic point measurement (APM) of tie points
- Pre-adjustment using the module „simultaneous solve" including blunder detection and re-measurements
- Semi-automatic or interactive point measurement (IPM) of additional tie points

(3) Adjustment and quality control

- Data transfer (image and ground control co-ordinates) to the external adjustment software
- Bundle block adjustment using BLUH (University of Hannover) including automatic blunder elimination and quality control
- Update of the orientation elements at the digital photogrammetric workstation

After APM, 65% of all measurements were successful, while, in total, 2192 points were automatically measured and 578 points were left unmeasured. These unmeasured points, which required editing, were neglected, in order to reduce editing to a minimum. In total, 10 points, which were detected as blunders, were re-measured using the module „simultaneous solve“ of HATS. In the bundle block adjustment, 146 observations with residuals over 20 microns were automatically eliminated. After the quality control (see also Kersten, 1999 for detailed description), which included the checking of the photo connections within and across strip direction, some points were additionally measured to connect lines 3 and 4 more strongly.

4.3. Digital triangulation with Match-AT

In order to use some automatic modules from HATS, an interface between HATS and Match-AT for data transfer before and after triangulation was developed by Swissphoto. Thus, all available triangulation parameters (camera data, interior orientation, initial values of orientation parameters, control point co-ordinates, etc.), which were already defined and imported in HATS, could be automatically transferred into the project file of Match-AT. The AT workflow using Match-AT is described in Krzystek (1998) in detail. The following workflow was used at Swissphoto:

(1) Preparation

- Automatic data transfer of triangulation parameters from HATS to project file of Match-AT
- Generation of image pyramids
- Definition and editing of the following parameters: project, photos, strips, block, points, matching, adjustment
- Semi-automatic measurement of four well distributed control points
- Initialisation of tie point areas in von Gruber positions including visual checks and editing

(2) AT measurements and integrated block adjustment

- Automatic point measurement (APM) of tie points through FBM/ABM least squares matching
- Integrated robust bundle block adjustment during all measurement processes
- Semi-automatic measurement of the control points

(3) Adjustment and quality control

- Data transfer (image and ground control co-ordinates) to the external adjustment software
- Bundle block adjustment using BLUH (University of Hannover) including automatic blunder elimination and quality control

The generation of the image pyramids was about 10 minutes per image and it took much longer than the automatic point measurements per image. All blunders were already eliminated within the bundle block adjustment of Match-AT, so that the results of the adjustment from BLUH were only used to analyse the block geometry.

4.4. Digital triangulation with Phodis-AT

The digital triangulation of block Wittenbach using Phodis-AT was performed at Zeiss in Oberkochen, Germany. The software and the workflow of the triangulation with Phodis-AT are described in Braun et al. (1996) in detail. To the author’s knowledge, the AT workflow of Phodis-AT is defined as follows:

(1) Preparation

- File preparation (camera, orientation parameter of camera stations, control points)
- Image data import including initial values of the orientation elements and image pyramid generation
- Automatic interior orientation
- Definition of AT parameters
- Visual check of image/strip overlap (quality control of initial values of exterior orientations)

(2) AT measurements

- Semi-automatic or interactive point measurement (IPM) of ground control points
- Automatic point measurement (APM) of tie points
- Semi-automatic or interactive point measurement (IPM) of additional tie points

(3) Adjustment and quality control

- Data transfer (image and ground control co-ordinates) to the external adjustment software
- Bundle block adjustment using BLUH (University of Hannover) including automatic blunder elimination and quality control

One signalised control point could not be measured due to bad visibility. Some tie points were additionally measured in the semi-automatic mode to connect lines 2, 3, and 4 more strongly. The final image co-ordinates of the digital aerial triangulation with Phodis-AT were delivered to Swissphoto. All blunders were already eliminated by analysing the results of the bundle block adjustment using PAT-B before data delivery.

4.5. Results from bundle block adjustment

Before the final bundle block adjustment, the image co-ordinates from all different systems were corrected for earth curvature and refraction. All observations (image co-ordinates, original ground control point co-ordinates) were adjusted in a bundle block adjustment with self-calibration using the bundle block adjustment program BLUH. As a priori value, the standard deviation of the ground control points were defined as s_{xyz} = 5.0 cm and the sigma naught was set to 5.0 microns, i.e. 0.4 pixel, to guarantee the same conditions for all adjustments.

System	Images	Strips	Control H/V	σ_0 [μm]	Obs.	Redund.	RMS X [cm]	RMS Y [cm]	RMS Z [cm]
AP DSR14	35	4	15/16	5.5	1256	521	3.3	3.2	6.2
Match-AT	34	4	16/16	5.3	7042	3314	4.1	3.7	6.1
Phodis-AT	34	4	15/15	5.6	15165	5292	5.3	4.5	6.7
HATS	34	4	16/16	6.6	4262	1775	2.2	3.8	5.0

Table 4: Results of the bundle block adjustments of block Wittenbach using BLUH.

The residuals (root mean square RMS) of the control points are summarised in Table 4. The results were similar for all systems, but with slight differences especially in the planimetry. The best results with respect to the RMS of the control points were achieved with HATS. The sigma naught aposterori σ_0 was in the same range (5.5 micron) for the DSR14, Match-AT and Phodis-AT, which corresponds to a precision of better than half of the pixel size for the digital systems, while the result for HATS was slightly worse (6.6 micron). It was expected that the analytical triangulation would yield the best results, so that it could be used as reference, but unfortunately the results were not better than the results of the digital systems.

In Table 5 the number of n-fold measured points are summarised to analyse the performance of each system for providing stable block geometry through sufficient point connections within the block. The number of n-fold points from the analytical triangulation is a typical result of manual measurements resp. manual connection of the block, although the number of 4-7 fold points could be much higher. The best performance for the connection of the photos in the triangulation block has been achieved by Match-AT due to the point clusters in the von Gruber positions. A slightly worse result was obtained by HATS with respect to the 3-5 fold points. Phodis-AT is very strong in the connection of the photos by 2 and 3 fold points, but the system has problems to achieve points with more than 3 rays. It was told to the author, that this was a weak performance of the version 2.0.1 of Phodis-AT, but the new versions (2.1.0. and the new 4.0) will search for points with more rays.

System	Number of photos/object point (percentage)											
	2	(%)	3	(%)	4	(%)	5	(%)	6	(%)	7	(%)
AP DSR14	38	(22.1)	83	(45.2)	15	(20.8)	10	(5.8)	14	(8.1)	12	(7.0)
Match-AT	410	(35.0)	537	(45.9)	94	(8.0)	90	(7.7)	40	(3.4)	-	
Phodis-AT	2231	(69.3)	889	(27.6)	74	(2.3)	21	(0.7)	5	(0.1)	-	
HATS	410	(54.1)	228	(30.1)	39	(5.1)	42	(5.5)	36	(4.8)	3	(0.4)

Table 5: Number of rays (percentage) in test block Wittenbach.

The empirical accuracy of each system was checked by using some control points as check points. Therefore, a minimum ground control point distribution of five points (one point at each corner of the block and one point in the centre) was used for block adjustment. The remaining eleven points were used as check points. The results of the empirical accuracy are summarised in Table 6. Surprisingly, the results from the analytical triangulation were very bad, which could be addressed to insufficient connections of the photos in the block. For the digital systems, the results were very similar and compared to the RMS values by a factor of up to four worse. It must be stated, that the minimum ground control distribution was not very optimal for block triangulation.

In the Figures 2-5 the following information is summarised:

- location of measured tie points (marked as Δ) and their typical distribution for each system (for Match-AT, they appear to be less, because many points almost coincide in the plot, i.e. point clusters)
- locations of camera stations or photo nadirs (marked as crosses in the lines) with the photo number and the flight lines (marked as lines from south to north)
- location of control points (marked as Δ) and their XYZ residuals (marked as vectors)

System	Control H/V	Check H/V	σ_0 [μm]	μ X [cm]	μ Y [cm]	μ Z [cm]
AP DSR14	5/5	11/11	5.5	17.2	22.8	41.0
Match-AT	5/5	11/11	5.4	8.6	11.2	18.0
Phodis-AT	5/5	10/10	5.6	10.8	11.6	20.3
HATS	5/5	11/11	6.7	9.7	10.1	16.1

Table 6: Empirical accuracy of block Wittenbach.

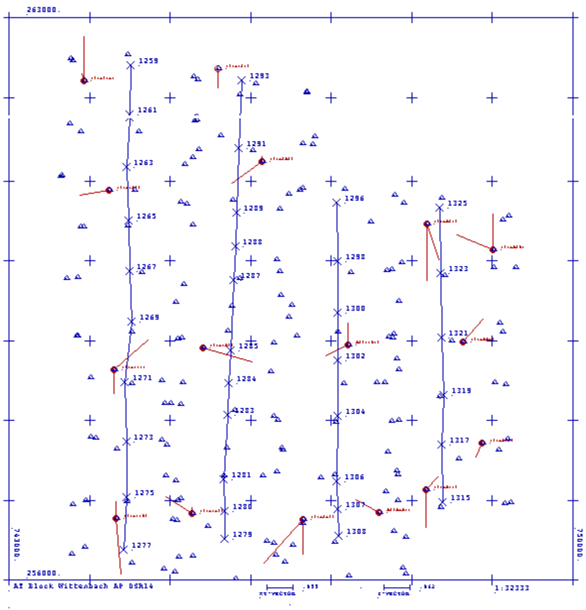

Figure 2: Analytical AT with Kern DSR14.

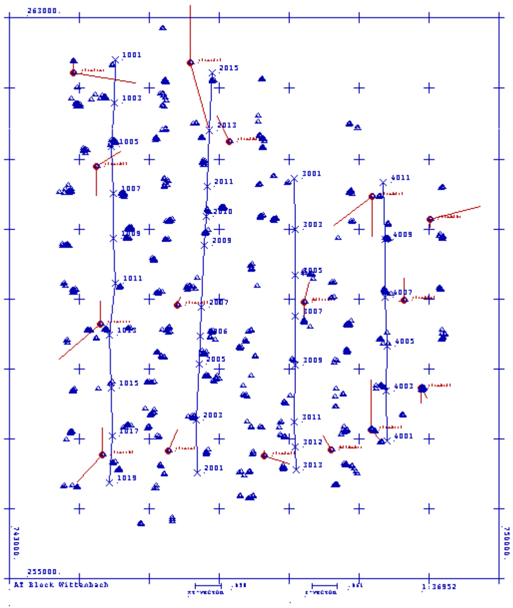

Figure 3: Digital AT with Match-AT.

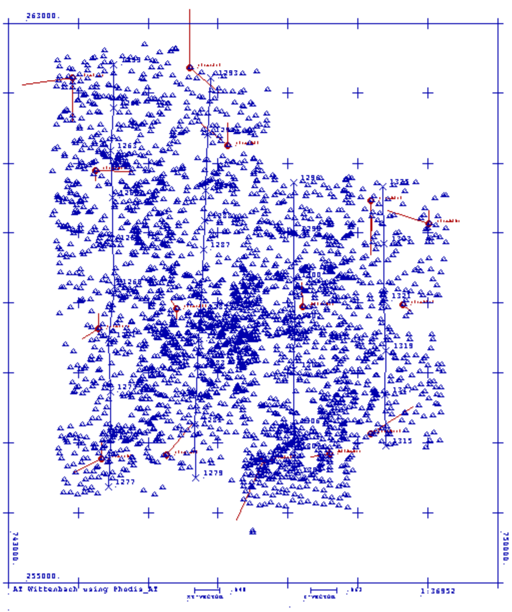

Figure 4: Digital AT with Phodis-AT.

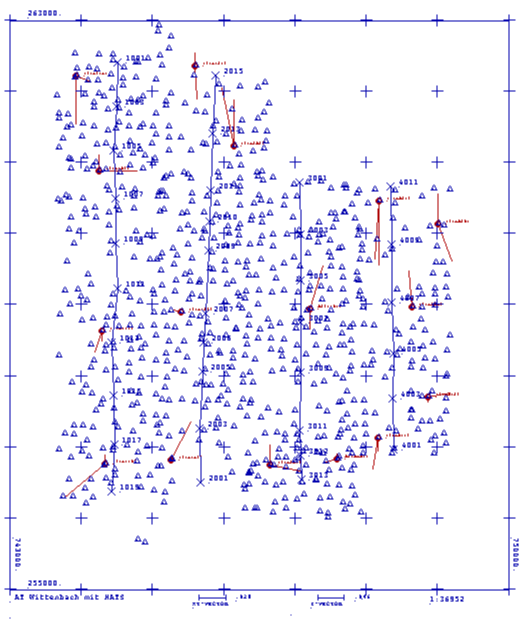

Figure 5: Digital AT with HATS.

These figures demonstrate clearly that much more tie points are measured through automated digital aerial triangulation, which yields a higher reliability in the exterior orientation, if a good blunder elimination is performed.

5. TIME REQUIRED

The time required for analytical and digital aerial triangulation of block Wittenbach is summarised in Table 7. In this table, only the operator’s time is counted, while the computation time of the computer for running batch processes, which is mostly done over night, is neglected. The triangulation of block Wittenbach was performed with a different operator for each system. The times for the triangulation with Phodis-AT were given by Zeiss, while for all other systems the elapsed time was estimated by the author.

In our investigations, it could be demonstrated that digital aerial triangulation of block Wittenbach was faster than analytical triangulation by up to a factor of 3. In general, this result was expected from other experiences, although not many direct comparisons have been published. But on the other hand, the elapsed time for triangulation using different digital systems varies. This could be attributed to the degree of automation of each system and to the different level of experience of each system operator. Especially, the post processing of the measurements provided many problems using HATS due to the large number of blunders in the measurements.

Other authors report good productivity for digital triangulation in flat terrain. DeVenecia et al. (1996) report a total working time of around 10 minutes per image, which was achieved with two test blocks using HATS. The two test blocks (Forssa and Wisconsin) have a large photo scale of around 1: 4’000 and represent a very flat area with maximum height differences of 10 meters. In alpine and Nordic regions, a similar production rate for digital systems as summarised in Table 7 was obtained by different authors (Kaeser et al. 1999, Kersten 1999, Urset and Maalen-Johansen 1999).

AT processing steps	**AP DSR14**	**DPW Match-AT**	**DPW Phodis-AT**	**DPW HATS**
Preparation [h]	5.0	1.5	1.0	1.5
AT Measurements [h]	10.5	5.5	3.5	4.5
Bundle block adjustment and quality control [h]	2.0	0.5	1.0	3.5
Total elapsed time [h]	17.5	7.5	5.5	9.5
Number of images	35	34	34	34
Elapsed time per image [min]	30.0	13.2	9.7	16.8

Table 7: Elapsed operator time for AT (Wittenbach) with different software packages.

6. CONCLUSIONS

Digital aerial triangulation of the Swiss test block Wittenbach could be performed using three different AT systems (Match-AT, HATS, and Phodis-AT). In comparison, the same block was triangulated at an analytical plotter (Kern DSR14 with ORIMA-T). The results (RMS, sigma naught aposterori σ_0, empirical accuracy, number of n-fold points), which were obtained using the four different systems with four different operators, were similar for all three digital systems and can be accepted as good for practical applications. With digital triangulation the same range of sigma naught could be achieved as for analytical triangulation. But, the efficiency of digital triangulation is much higher (approx. a factor 2-3). Furthermore, the adjusted orientation parameters are much more reliable than derived from analytical triangulation due to the higher number of measured points per image and their position in the image with the assumption, that all blunders are eliminated. In general, it is very difficult to compare triangulation software packages, if the triangulation is performed by different operators with different level of experience.

The comparison of HATS and Match-AT yielded the following results, which might be influenced by the author’s subjective opinion:

- Digital triangulation using both systems provides a reliable result of the photo connections within the block.
- The precision (sigma naught) of digital aerial triangulation using both systems is at the level of analytical triangulation.
- HATS provides more automation in the preparation by Swissphoto’s customised and modified approach.
- The quality of measured points by the combination of feature and area based matching is higher.

- The results obtained by both systems are similar, although the point distribution is different (point clusters vs. homogeneous point distribution).
- For the measurements of Match-AT less post processing is necessary.
- Digital triangulation with Match-AT is faster.
- The integration of bundle block adjustment software in the measurement phase (Match-AT) is the better solution.
- Both commercial systems do not provide an easy-to-use graphical user interface for quality control of the triangulation results.
- Both systems do not provide template matching of signalised points to achieve higher accuracy.

However, there is still potential for more improvements in digital AT to increase the productivity, so that a triangulation rate of better than 5 minutes per image could be possible in the future. This can also be achieved, if precise direct measurements of the orientations elements by GPS/INS will be available, to start with a better approximation for the automatic point transfer.

REFERENCES

BRAUN, J., TANG, L., DEBITSCH, R., 1996. PHODIS AT - An Automated System for Aerotriangulation. *Int. Archives of Photogrammetry and Remote Sensing*, Vol. 31 (B2), pp. 32-37.

DEVENECIA, K., MILLER, S., PACEY, R., WALKER, S., 1996. Experiences with a Commercial Package for Automated Aerial Triangulation. *Proceedings of ASPRS/ACSM Annual Convention*, Vol. 1, pp. 548-557.

HARTFIEL, P., 1997. Higher Performance with Automated Aerial Triangulation. *Photogrammetric Week '97*, Eds. Fritsch/Hobbie, Wichmann Verlag Karlsruhe, pp. 109-113.

JACOBSEN, K., WEGMANN, H., **1998**. Experiences with Automatic Aerotriangulation. *Proceedings of ASPRS-RTI Annual Convention*, Tampa, USA, March 30 - April 3.

KAESER, C., EIDENBENZ, C., BALTSAVIAS, E., 1998. Evaluation and Testing of Several Digital Photogrammetric Systems for System Acquistion by a National Mapping Agency. *International Archives of Photogrammetry and Remote Sensing*, Vol. 32, Part 2, pp. 140-148.

KAESER, CH., CZÀKA, Th., KUNZ, Th., 1999. Digital Aerotriangulation for Map Revision with MATCH-AT. *Proceedings of the OEEPE Workshop on Automation in Digital Photogrammetric Production*, Paris, June 21-24.

KERSTEN, Th., 1999. Digital Aerial Triangulation with HATS. *Proceedings of the OEEPE Workshop on Automation in Digital Photogrammetric Production*, Paris, June 21-24.

KERSTEN, Th., O'SULLIVAN, W., 1996. Experiences with the Helava Automated Triangulation System. *Int. Archives of Photogrammetry and Remote Sensing*, Vol. 31 (B3), pp. 591-596.

KERSTEN, Th., HAERING, S., 1997a. Automatic Interior Orientation of Digital Aerial Images. *Photogrammetric Engineering & Remote Sensing*, Vol. 63 (8), pp. 1007-1011.

KERSTEN, Th., HAERING, S., 1997b. Efficient Automated Digital Aerial Triangulation Through Customisation of a Commercial Photogrammetric System. *Int. Archives of Photogr. and Remote Sensing*, Vol. 32, Part 3-2W3, pp. 72-79.

KERSTEN, Th., HAERING, S., O'SULLIVAN, W., 1998. Digital Aerial Triangulation in Alpine Regions - A Challenge. *International Archives of Photogrammetry and Remote Sensing*, Vol. 32, Part 2, pp. 149-156.

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

KRZYSTEK, P., HEUCHEL, T., HIRT, U., PETRAN, F., 1996. An Integral Approach to Automatic Aerial Triangulation and Automatic DEM Generation. *Int. Arch. of Photogr. and Remote Sensing*, Vol. 31 (B3), pp. 405-414.

KRZYSTEK, P., 1998. Automatic Aerial Triangulation - Conceptual aspects and new investigations. *3rd Course on Digital Photogrammetry*, University of Bonn, Feb. 9-13.

MASALA, B., 1999. Experiences on Automatic Digital Aerotriangulation. *Proceedings of the OEEPE Workshop on Automation in Digital Photogrammetric Production*, Paris, June 21-24.

URSET, A., MAALEN-JOHANSEN, I, 1999. Automatic Triangulation in Nordic Terrain - Experiences and Challenges with MATCH-AT. *Proceedings of the OEEPE Workshop on Automation in Digital Photogrammetric Production*, Paris, June 21-24.

WANG, Y., 1998. Principles and Applications of Structural Image Matching. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 53, No.3, pp. 154-165.