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Experiences with Semi-automatic Aerotriangulation on Digital Photogrammetric Stations

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ABSTRACT

With the development of higher-resolution scanners, faster image-handling capabilities, and higher-resolution screens, digital photogrammetric workstations promise to rival conventional analytical plotters in functionality, i.e. in the degree of automation in data capture and processing, and in accuracy. The availability of high quality digital image data and inexpensive high capacity fast mass storage offers the capability to perform accurate semi-automatic or automatic triangulation of digital aerial photo blocks on digital photogrammetric workstations instead of analytical plotters.

In this paper, we present our investigations and results on two photogrammetric triangulation blocks, the OEEPE (European Organisation for Experimental Photogrammetric Research) test block (scale 1: 4'000) and a Swiss test block (scale 1: 12'000) using digitized images. 28 images of the OEEPE test block were scanned on the Zeiss/Intergraph PS1 and the digital images were delivered with a resolution of 15 µm and 30 µm, while 20 images of the Swiss test block were scanned on the Desktop Publishing Scanner Agfa Horizon with a resolution of 42 µm and on the PS1 with 15 µm. Measurements in the digital images were performed on the commercial Digital Photogrammetric Station Leica/Helava DPW770 and with basic hard- and software components of the Digital Photogrammetric Station DIPS II, an experimental system of the Institute of Geodesy and Photogrammetry, ETH Zurich. As a reference, the analog images of both photogrammetric test blocks were measured at analytical plotters. On DIPS II measurements of fiducial marks, signalised and natural tie points were performed by least squares template and image matching, while on DPW770 all points were measured by the cross correlation technique. The observations were adjusted in a self-calibrating bundle adjustment. The comparisons between these results and the experiences with the functionality of the commercial and the experimental system will be presented.

Keywords: Aerotriangulation, Digital Photogrammetric Station, self-calibrating bundle adjustment

1 Introduction

Different investigations were performed in aerotriangulation since the first digital photogrammetric systems were available on the market in the 1980's. The digital era in aerotriangulation started with point transfer by digital image correlation on analytical plotters. Therefore, sub-scenes of photos were digitized by CCD-cameras, which were installed on some analytical plotters, i.e. Planicomp C100 (*Pertl, 1984; Ackermann/Schneider, 1986*), Kern Correlator, based on the DSR11 (*Bethel, 1986*), and Prime-Wild System 9 (*Wilkins, 1990*). At the Conference on Fast Processing of Photogrammetric Data in Interlaken *Helava (1987)* introduced the Digital Comparator Correlator System (DCCS), which was developed for automatic selection and measurement of tie points for block triangulation. Practical experiences and re-

sults, i.e. also in aerotriangulation, with the DCCS at the Survey Department of the Netherlands are reported by *Han (1992)*. *Agnard et al. (1992)* reported on a softcopy aerotriangulation with a block of two strips, each consisting of eight models, using the PC-based Digital Video Plotter (DVP) of Leica.
Digital methods offer the capability to automate several procedures in aerotriangulation. Techniques from image processing, computer vision, and photogrammetry have successfully been employed for facilitating automatic procedures in digital aerial triangulation such as interior orientation *(Schickler, 1993; Lue, 1995; Kersten/Haering, 1995)*, relative orientation *(Tang/Heipke, 1993)* and, point transfer in photogrammetric block triangulation. *Tsingas (1991)* showed first results of automatic point transfer in aerial triangulation using point selection with an interest operator and automatic tie point measurement and transfer for a 5 x 5 block. For image data acquisition, a flight was simulated over an artificial model with a CCD-camera. Another system for automatic point transfer in aerotriangulation, developed on an Intergraph Station at the Ohio State University, is introduced by *Schenk (1995)*.
Although automatic procedures for interior and relative orientation are already realized, it is still very difficult to automate the absolute orientation *(Haala/Vosselman, 1992; Schickler, 1992)*. This mainly depends on the identification and measurement of control features which requires sufficient knowledge on these features. For automatic recognition and localisation of signalised points in digital aerial photos an artificial neural network approach is presented by *Këpuska/Mason (1991)*. Due to the different orientations, backgrounds, scales, and radiometric and geometric deformations of the targets, the used feed-forward network using a back propagation algorithm must be trained with a very large number of cases that adequately reflect the variations of the target and non-target pattern. After training 85% of the signalised points appearing in 34 images were recognised in these investigations. Due to elapsed time and success rate these results are not very satisfactory for aerial triangulation, and one still needs an operator’s input for the assignment of control point numbers.
To get an overview of the current state-of-the-art in digital aerotriangulation and to show the potential of the aerotriangulation using high quality digital imagery with practical results the OEEPE test “Aerotriangulation using digitized images” was established. For this research project investigations and measurements using the OEEPE image data were also performed at the Institute of Geodesy and Photogrammetry of the ETH Zurich. Additionally, image data of a second block - Luzzone (Switzerland), whose data acquisition was conducted during the diploma surveying field course of ETH Zurich in summer 1994 - were processed.
In the following sections 2 and 3 both, the used hardware and software and the used data sets, are introduced. The image point measurements are described in section 4, while in section 5 the results from the bundle adjustment are presented.

2 Hardware and software

All measurements in the digital images for aerial triangulation of the two blocks were performed on the commercial Digital Photogrammetric Station Leica/Helava DPW770 and with basic hard- and software components of the experimental Digital Photogrammetric Station DIPS II *(Gruen/Beyer, 1990)* of the Institute of Geodesy and Photogrammetry, ETH Zurich.
The used DPW770 is based on a general purpose computer with console monitor (Sun Sparc 10/41) and keyboard, a graphics processor, an extraction monitor (Tektronix SGS 625 polarisation screen), and additional operator control by mouse and trackball. Peripheral devices are a tape drive (video8), a CD-ROM drive, and disk drives (currently with two additional external disks a total of 4.5 GByte are available). The used software release (SOCET Set 2.2.4) works under the UNIX operating system SunOS 4.1.3. Following software modules were used:

- Import of digital images and minification (image pyramid).
- Mono- and Stereo-Display of images.
- Semi-automatic and automatic interior orientation.
- Exterior orientation including semi-automatic measurements by cross-correlation.

DIPS II consists of 2 file servers and 13 Sun workstations linked to each other via Ethernet with some external components for digital image acquisition and output. DIPS II serves as a platform for all research and development projects of the Institute. At the current stage, a total of 15 GByte disk capacity for data storage is available. For both tests we could use effectively 2.5 GByte.

The relevant programs used for the measurements, which were performed for the aerial triangulation, are summarized in the following:

- A viewing tool for the display of the images, manual measurement of image points, and extracting Region Of Interest (ROI) from images.
- A Least Squares Matching tool for template matching of fiducial marks and signalised points, and image matching of tie points.

For reduction of measurement data following programs were used:

- An affine transformation for the transformation from pixel to image coordinate system
- A bundle adjustment with self calibration and analysis of measurements.

Area:	**Forssa (Southern Finland)**	**Lago di Luzzone (Switzerland)**
Area covered:	**1.5 x 2.5 km^2**	**5 x 3 km^2**
Ground height:	**100 m**	**1600 m**
Flying height above ground:	**600 m**	**2500 m**
Camera:	**Wild RC 20, 15/4 UAGA-F, No. 13118**	**Wild RC 20, 21/4 NAGA-F, No. 7171**
Photo scale:	**1: 4’ 000**	**1: 12’ 000**
Forward/side overlap:	**60%/34%(24% - 49%)**	**60%/60%**
Number of strips:	**4**	**3**
Number of images/strip:	**7**	**7, 6, 7**
Date of flight:	**May 3, 1989, 11.40 am**	**August 9, 1994, 11.40 am**
Film/digital imagery:	**positive colour/greyscale**	**negative/greyscale**
Scanner:	**Zeiss/Intergraph PhotoScan 1**	**Zeiss/Intergraph PS 1, Agfa Horizon**
Pixel size:	**15 µm/30 µm**	**15 µm/42 µm**

Table 1: Flight and block data of the OEEPE (left) and LUZZONE (right) test image data

3 Triangulation test data and image quality

For the OEEPE test a block of 28 aerial photographs has been scanned by the Zeiss/Intergraph PhotoScan 1 as greyscale images. The photographs have been scanned with a pixel size of 15 µm, which occupies disk storage of 256 MByte per image. A data set with a pixel size of 30 µm (64 MByte) was created from the previous data set.

20 aerial photographs of the Luzzone test block have been scanned with the Zeiss/Intergraph PhotoScan 1 using a pixel size of 15 µm (236 MByte per image), and with the Agfa Horizon Scanner using a pixel size of 42 µm (29 MByte per image) as greyscale images.

The relevant flight and block data for both projects are summarized in Table 1. The OEEPE photogrammetric block was flown above a flat area (height differences under 5 m), while the Luzzone block repre-

sents a mountainous area (height differences up to 1300 m). In addition to the image data, camera calibration certificates, and 3-D object coordinates of 14 (OEEPE) resp. 12 (Luzzone) control points were available. Additionally, for the OEEPE test block approximate image coordinates of the signalised control and check points were delivered by the OEEPE project pilot center.
The radiometric quality of the digital imagery was different: in the OEEPE image data grey value differences between neighbouring zones and vertical stripes could be shown *(Kersten/Stallmann, 1994)*, but effects of resulting positioning errors were not comprehensively tested. Radiometric differences and horizontal stripes were detected in the Luzzone images, which were scanned with the PS1. Additionally, these images appeared too dark on the monitor. However, in the Luzzone images, scanned with the Agfa Horizon, problems with the radiometric performance could not be detected.

4 Image point measurements

For aerial triangulation, the following points were measured in aerial images: fiducial marks for transformation into image coordinates, signalised points for transformations into object space, and tie points in strip and across strip direction for reliable connection of the images. The following measurements were performed:

- OEEPE image data 15 µm with DPISII
- OEEPE image data 30 µm with DIPSII
- Luzzone image data 15 µm with DPW770 and DIPSII
- Luzzone image data 42 µm with DPW770
- Luzzone negatives with Analytical plotter Leica AC3

4.1 Digital Photogrammetric Station DPW 770 (Helava/Leica)

With the DPW770 image points were measured in the images (15 and 42 µm) of the Luzzone block. The triangulation at the DPW770 works along the principle of the relative orientation of two consecutive images. The DPW provides optionally measurements in stereo display or in split screen mode. From the operator's point of view the split screen mode was chosen as the better option for measurements. Following working procedure was performed:

- Data input: Loading and converting of digital images and generation of image pyramids
- Interior orientation: optional semi-automatic or fully operational automatic measurements
- Triangulation:
  - rough manual positioning of tie points in the von Gruber positions in two overview images (stereo pair)
  - semi-automatic measurements of tie and signalised points in split screen mode with visual control
  - triangulation in strip and across strip direction for reliable tying of images
- Computation of orientation for all already measured images (optional)

For image point measurements the hierachical relaxation correlation (Helava, 1987), which is a hierachical stereo correlation, was used in the semi-automatic mode. The point was manually measured in one image and automatically by cross correlation in the corresponding image using initial values, which were set by the operator's cursor.
Advantages of the DPW770 for aerotriangulation are:

- Superimposition of already measured points and candidates of previous images/strips
- Measurements in two images across strip direction for reliable tying

Problem areas are:

- No on-line computation of residuals
- No automatic point transfer
- Display of at most two images on the monitor
- Redisplay of images at the extraction monitor is too slow (up to 20 seconds)
- Due to a lack of an image data compression there is insufficient disk capacity for images with higher resolution (15 µm)

4.2 Digital Photogrammetric Station DIPS II

The OEEPE image data set with 15 µm resolution was measured with DIPS II using an old version of the software package with SunView as the graphical user interface (GUI), while the 30 µm data set and the Luzzone block (15 µm) was measured with a modified and an improved version under OpenWindows. While in the previous program only ROIs could be used for measurements, the improved and modified software offered the option to display multiple images as an overview on the screen and to perform each measurement in zoomed parts of the multiple images in one step.

The measurements in the OEEPE 15 µm image data set using the SunView GUI are described in *(Kersten/Stallmann, 1994)*. For point positioning in aerial triangulation only parts of the whole image are of interest for the measurements, i.e. fiducial marks, signalised points and, tie points in strip and across strip direction. The input and output of such large digital images (256 Mbyte for the 15 µm scanned images) and their display will use a lot of disk storage capacity and consume long I/O time, i.e. to read images from tape, as well. Due to these aspects, the concept in our investigations was to use only ROIs of the images for the measurements. Therefore, patches of the eight fiducial marks, all visible signalised points and the selected tie points were automatically extracted in each digital image using the delivered pixel coordinates as initial coordinates for each patch center. All extracted ROIs were stored on disk, which saved 96% of the disk space compared to a storage of the whole digitized images. Image enhancement was not performed on any ROI.

For the OEEPE 30 µm image data set, which was measured with the new software version using an OpenWindows GUI., following procedure was performed:

- Fully automatic interior orientation of the whole block in one step
- Display of a maximum number of images on the screen: 3 (2 in strip and 1 across strip direction)
- Image matching of natural tie points
- Template matching of signalised points
- Affine transformation from pixel to image space

The image point measurements for all points (fiducials, signalised and tie points) were performed by matching. The used algorithm is known as constrained Least Squares image Matching (LSM), which allows point measurements with subpixel accuracy, and is described in *Gruen/Baltsavias (1988)*. In these investigations, the algorithm was used in its unconstrained mode, known as template matching as one image provides an artificial and ideal version of the point to be located in the others.

The matching was performed interactively using a window-based interface to the algorithm. This allows all algorithm parameters to be set to optimum values for a particular matching problem, plus assessment of the result by visual inspection. The visual inspection provided a quality control of the measurements by the operator: if a point could not be matched satisfactorily with the chosen parameters, then an alternative optimum set was found - usually a smaller or larger patch size or a restricted image shaping transformation.

Artificial templates were generated for fiducial marks and for signalised points. For the matching of selected tie points one point was chosen as the template in order to locate the other points in the related, overlapping image patches.

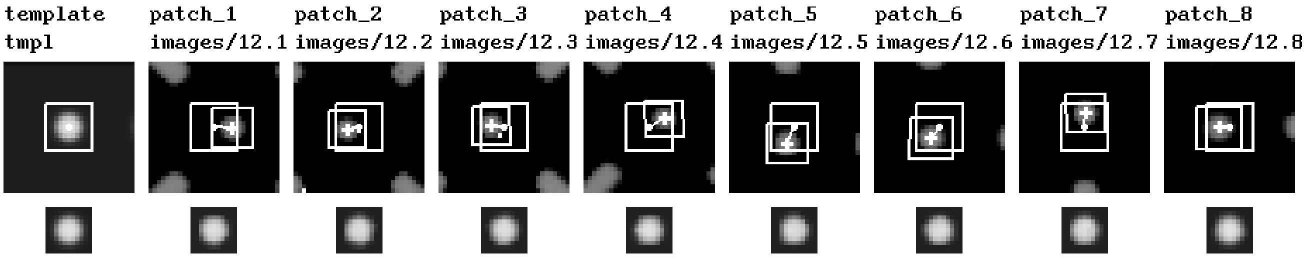

Figure 1: Template matching of eight fiducial marks (15 µm image data)

The fiducial mark signals were well defined and the matching could be done without any problems. In Figure 1 the upper large images show the matching between the template and the patches indicating the initial position as a point and the final solution as a cross, while the lower small images depict visually the matching results.

While the fiducial marks in all OEEPE 15 µm images were measured semi-automatically, for the others data sets the interior orientation was determined fully automatically. The algorithm and the program AUTO_IO that were used, are described in *Kersten/Haering (1995)*.

The signalised points were not so straightforward to match as fiducial marks; especially for the OEEPE data sets their images show a great variety in shape and contrast. On the average, the targets occupied a square of 5-7 pixels (30 µm) resp. 10-14 pixels (15 µm). The original size of the arms of the OEEPE cross shaped targets are 10 cm x 60 cm on the ground. In the Luzzone project one square meter disks were used for signalisation, which are imaged as targets with a size of 8 x 8 pixels (15 µm).

The quality of the 30 µm digital image material (OEEPE) allowed only template matching with two translation parameters using a patch size of 7 x 7 pixels. Some targets were measured manually. The template matching of four signalised points (30 µm image data) is shown in Figure 2a and the visual inspection of the matching results demonstrates the low quality of the targets in the 30 µm image data. In the high resolution patches (OEEPE 15 µm) all targets could be matched with the same template using a conformal transformation and an average patch size of 15 x 15 pixels. Figure 2b shows the template matching of seven targets. The visual inspection of the matching results (Figure 2a and 2b) indicates the different quality of the targets in both image data sets. Although some targets were badly imaged, they could be matched successfully by providing good approximations or by using different patch sizes.

In the Luzzone images the 12 targets were very well defined and the least squares template matching worked successfully for each target.

For image matching of tie points one tie point was used as the artificial and ideal version of the point to be located in the other patches. The operator could mostly select well defined points, in general, points in flat areas, and the matching could be performed without problems. All points were matched in patches with a size of 15 x 15 pixels using affine transformation. For reliability reasons two tie points were matched in each ROI of 512 x 512 pixels, which were extracted in the von Gruber positions. The image matching of four tie points in images of two strips is illustrated in Figure 3.

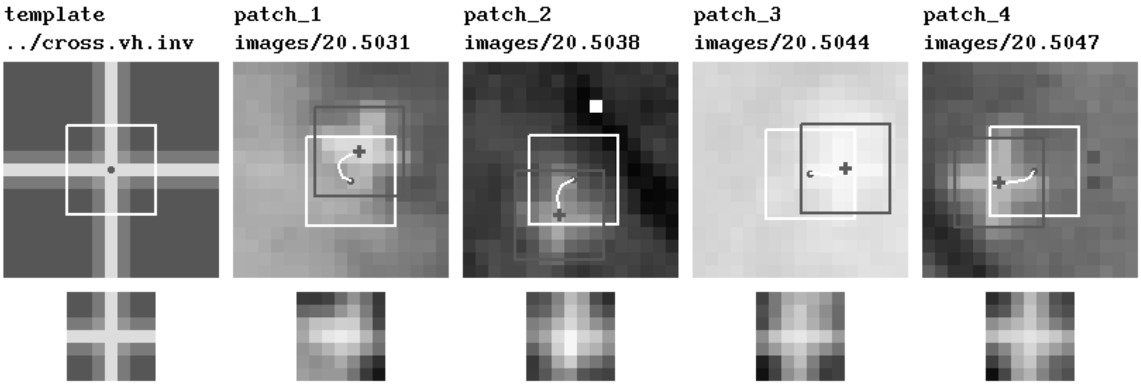

Figure 2a: Template matching of four signalised points (30 µm image data)

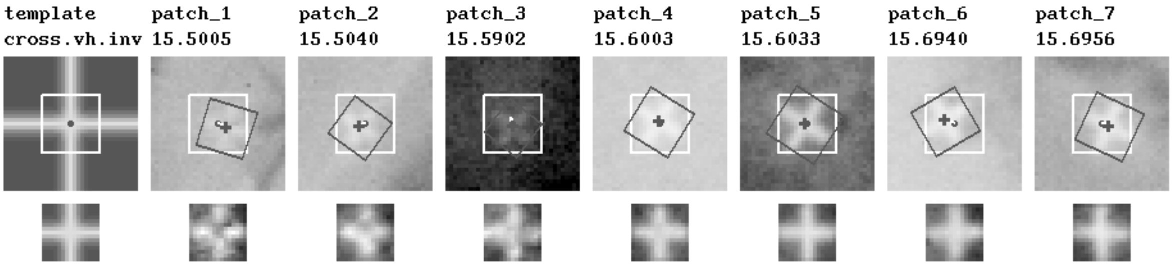

Figure 2b: Template matching of seven signalised points (15 µm image data)

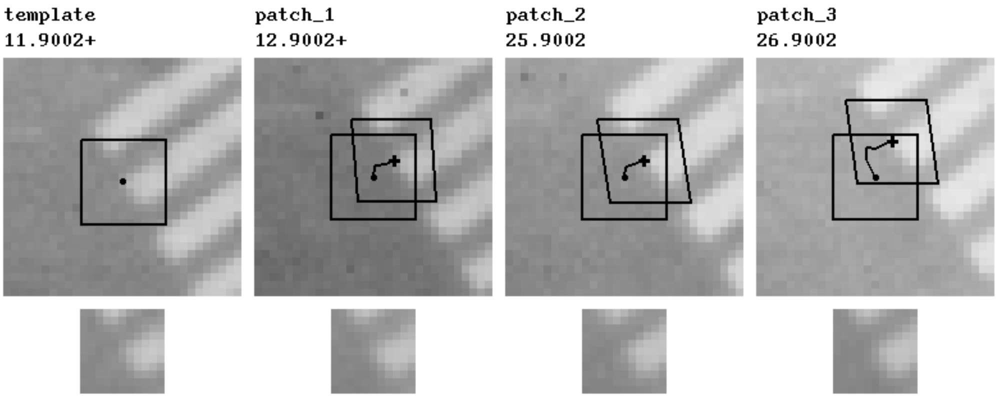

Figure 3: Multiple image matching of four tie points (30 µm image data)

Advantages of the procedure using DIPS II are:

- Superimposition of already measured points
- Measurements in multiple images in strip and across strip direction for reliable tying
- Visual quality control of template and image matching

Problem areas are:

- No on-line computation of residuals
- Automatic point transfer neither in nor across strip direction
- Too many windows on one screen when using multiple images for triangulation

4.3 Analytical Plotter Leica AC3

The negatives of the Luzzone block were conventionally measured at the Analytical Plotter Leica AC3 by a student for a diploma thesis on comparison of the analytical and digital aerial triangulation *(Kohli, 1994)*. The three strips were measured in strip direction, while the across strip connection was performed in the second and third strip using points from the previous strips.
Advantages:

- Measurements in images (negatives or positives) with highest possible resolution
- Computer supported measurements including semi-automatic point transfer in strip direction

Problem areas:

- Only manual point transfer across strip direction
- No on-line computation of residuals
- No automatic point transfer
- Simultaneous measurements in at most two aerial images

5 Bundle block adjustment

The adjustment of image coordinates was performed with the software package BUN, which is a collection of more than 40 programs, separated in four parts, namely preprocessing of data, bundle adjustment with self calibration, analysis of results, and plot facilities. The mathematical background of the bundle adjustment in this program, a FORTRAN version and further development of the program MBOP from the Technical University of Munich, is described in *Gruen (1976)*. The bundle adjustment program, the main part of BUN, allows the automatic computation of initial values including checks for gross errors and their automatic elimination at that stage. For the compensation of systematic errors in aerial photos the 12 Additional Parameters (AP) of *Ebner (1976)* or the 44 APs of *Gruen (1978)* can be used optionally in the adjustment. Both photogrammetric blocks, the OEEPE images and the Luzzone images, were adjusted without and with self-calibration using both additional parameter sets.
The image coordinates were introduced into the adjustment with a standard deviation of 5 µm (sigma a priori), while the standard deviation of all control point coordinates was 20 mm (OEEPE) resp. 15 mm in plane and 53 mm in height (Luzzone). To fix the datum in the adjustment, all control points, 14 (OEEPE) and 12 (Luzzone), were used.
The results of the adjustments of the OEEPE data are summarized in Table 2. For the high resolution image data (15 µm) the self-calibrating bundle adjustment (12 AP) yielded about 3.7 µm standard deviation for the measured image point observations and a theoretical precision of σ_x = 16 mm, σ_y = 19 mm, and σ_z = 39 mm for new points. In planimetry the empirical accuracy of check points is about a factor of 1.5 worse (μ_x = 26 mm, μ_y = 24 mm), while in height the empirical accuracy confirms the obtained theoretical precision (μ_z = 38 mm). The results obtained with the 30 µm image data is about a factor of 2 worse compared to results with the 15 µm imagery, which represents the factor of resolution difference between both image data sets. The use of 44 APs only improved the empirical accuracy of 30 µm image data slightly. In comparison, the results from the 15 µm image data correspond to results (σ_0 = 3.5 µm, μ_x = 21 mm, μ_y = 24 mm, μ_z = 38 mm), which were obtained by measurements with the Analytical Plotter Leica BC1 at the Swiss Federal Institute of Technology in Lausanne *(Jaakkola/Sarjakoski, 1994; Koelbl, 1994)*. Furthermore, the 30 µm images were also measured with Leica/Helava DPW 650, a mono station, in Lausanne. These results (σ_0 = 10 µm, μ_x = 62 mm, μ_y = 48 mm, μ_z = 95 mm) are slightly worse than the results obtained with DIPSII (σ_0 = 6.6 µm, μ_x = 43 mm, μ_y = 54 mm, μ_z = 72 mm).

V	P	AP	Points per image	Ch p	Ch h	C	$\hat{\sigma}_0$ [μm]	Precision from adjustment in object space [mm] New points			Empirical accuracy [mm] Check points		
								σ_x	σ_y	σ_z	μ_x	μ_y	μ_z
1	15	0	24	71	62	14	3.9	16.0	18.4	39.3	35.1	29.1	41.7
2	15	12	24	71	62	14	3.7	15.9	18.7	38.5	25.5	23.5	37.7
3	15	44	24	71	62	14	3.8	16.7	20.3	42.7	24.7	32.9	39.1
4	30	0	26	68	59	14	6.6	26.5	31.9	65.9	44.2	53.8	77.5
5	30	12	26	68	59	14	6.5	27.9	34.1	68.1	44.8	50.6	76.2
6	30	44	26	68	59	14	6.6	28.7	35.7	75.2	43.2	53.6	72.0

V .... Version
P .... Pixel size of the image data [μm]
AP .... Number of additional parameters
Ch .... Number of check points (p=plane, h=height)
C .... Number of Control points
$\hat{\sigma}_0$ .... Sigma a posteriori
σ_{xyz} .... Theoretical precision in object space (from Q_{xx})
μ_{xyz} .... Empirical accuracy in object space

Table 2: Results from the bundle adjustment of the OEEPE test data (image scale 1: 4’000)

Jaakkola/Sarjakoski (1994) summarize preliminary results of the whole OEEPE research project.
The results of the adjustments of the Luzzone data are summarized in Table 3. However, due to the absence of check points only the precision from adjustment can be compared between the three measurement devices.
Measurements with DIPSII yielded the best results (σ_0 = 3.3 μm, σ_x = 4 cm, σ_y = 4 cm, σ_z = 12 cm). In comparison, the precision obtained from measurements with DPW770 is slightly worse than the precision from DIPSII measurements, which partly can be addressed to the lower number of points and mainly to the different semi-automatic measurement techniques (least square matching resp. cross correlation). The measurements with the AC3 are by a factor of 2 worse than results with both Digital Photogrammetric Stations using the 15 μm imagery. This can mainly be caused by the operator, who had no experiences in measuring on an Analytical plotter, and who, in fact, measured the first time a photogrammetric block after a short training phase. Additionally, it was difficult to center precisely the measuring mark on the large disks of the signalised points in the negatives. For the Luzzone block an experienced operator might increase the precision by a factor of 2.
On the other hand, it could be expected that the results from the 42 μm imagery measured with the DPW770 are significantly worse than with the higher resolution imagery. This worse results can be attributed to the geometrically unstable digitizing of the 42 μm image data on the Afga Horizon scanner, which was used without calibration and can cause errors up to 100 μm. Calibration procedures for the used Agfa Horizon scanner are currently in preparation *(Baltsavias/Crosetto, 1995)*, which might significantly increase the geometric precision for the digitizing with the Agfa scanner. The use of 44 APs in the adjustment could improve the precision by a factor of 3. It is supposed that the 44 APs might compensate systematic errors from the scanning process. Further tests with the scanner must be performed to confirm

this hypothesis.

V	P	AP	Instr.	# points	# points per image	C	$\hat{\sigma}_0$ [µm]	Precision from adjustment in object space [cm]		
								New points		
								σ_x	σ_y	σ_z
1	-	0	AP AC3	87	18	12	5.8	7.9	7.8	20.5
2	-	12		87	18	12	5.7	8.3	8.4	21.7
3	-	44		87	18	12	5.9	9.0	9.3	24.0
4	15	0	DIPSII	152	26	12	3.8	4.3	4.6	13.0
5	15	12		152	26	12	3.9	4.6	4.9	13.7
6	15	44		152	26	12	3.3	4.2	4.4	12.4
7	15	0	DPW770	119	21	12	5.0	5.1	5.6	14.6
8	15	12		119	21	12	4.9	5.4	5.9	15.3
9	15	44		119	21	12	4.5	5.2	5.6	14.6
10	42	0	DPW770	134	21	12	49.1	62.5	64.1	187.2
11	42	12		134	21	12	41.1	54.8	56.4	163.7
12	42	44		134	21	12	14.1	19.9	20.5	59.8

V ....Version
P ....Pixel size of the image data [µm]
AP ....Number of additional parameters
C ....Number of control points
$\hat{\sigma}_0$ ....Sigma a posteriori
σ_{xyz}..............Theoretical precision in object space (from Q_{xx})

Table 3: Results from the bundle adjustment of the Luzzone data (image scale 1: 12’000)

6 Conclusions

The investigations and results of the performed aerotriangulation using digital images of two photogrammetric blocks demonstrate the capability and potential of the digital method which is comparable to traditional analytical triangulation in efficiency, reliability and accuracy.

In our investigations the two test blocks showed, that the result of the bundle adjustment with the higher resolution imagery (15 µm) is comparable to results of adjustments with measurements on Analytical Plotters. For the OEEPE 15 µm data the digital triangulation yielded an accuracy from check points of μ_x = 26 mm, μ_y = 24 mm, and μ_z = 38 mm, which corresponds to the result obtained with an Analytical Plotter (μ_x = 21 mm, μ_y = 24 mm, μ_z = 38 mm). With the Luzzone images the experimental DIPSII yielded a better result (σ_x = 4 cm, σ_y = 4 cm, σ_z = 12 cm) than the commercial DPW770 (σ_x = 5 cm, σ_y = 6 cm, σ_z = 15 cm). This indicates that for aerotriangulation the image point measurement with least-square matching implemented in DIPSII is slightly superior to the cross correlation technique used on DPW770.

Requirements for precise aerotriangulation is digitizing of the images using an accurate photogrammetric scanner or a calibrated low-cost scanner and the use of high resolution imagery of probably better than 25 µm. Image point measurements using least-squares matching can be recommended.
In future, following procedures of digital aerial triangulation are already or will become more and more a standard software implementation in Digital Photogrammetric Stations, which definitely will improve the efficiency of the triangulation method:

- Fully operational automatic interior orientation
- Automatic relative orientation and point transfer
- One-line triangulation using sequential estimation technique for on-line residual display and for quality control by blunder detection

Assuming that digital triangulation can reach the same accuracy potential as the conventional method, the user will accept and will buy digital systems in future, if the efficiency can be increased with the degree of automation in digital triangulation. This will cause an increasing replacement of Analytical Plotter by Digital Photogrammetric Stations for photogrammetric production processes.
To increase the degree of automation in aerotriangulation following procedure could be possible: After an automatic interior orientation and a relative orientation including point transfer for all digital images of the photogrammetric block only a few signalised points will be measured, which yield the datum for the adjustment. Moreover, using the adjusted exterior orientation and the ground point coordinates of the signalised points approximate image coordinates of the remaining targets can be determined for each image. These image coordinates can be used as initial values for the automatic template matching of the control points. On the other hand, photogrammetric blocks flown with GPS/INS systems can reduce the need to only a few control points.

7 Acknowledgments

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