AUTOMATIC AERIAL TRIANGULATION – REPORT OF A LARGE PROJECT UNDER DIFFICULT CONDITIONS

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ABSTRACT:

The *Provincia Autonoma di Bolzano – Alto Adige* commissioned the bidding group *GEOSIGMA s.r.l.*, *GEOMATICA s.r.l.* and *Ingenieurgemeinschaft Vermessung AVT-ZT GesmbH* to produce a GIS-data base of parts of their province. It was demanded to create topographic data for technical base map in the scales 1:5.000 and 1:10.000. For the data acquisition an existing photo flight of about 2.500 images was used.
Following, the most critical parameters of the specific block adjustment are given:
- An alpine and topographically very challenging region with height differences up to 2.000 m within one image.
- The photo flight mission was carried out over a period of about 4 months. 4 different aerial cameras have been used for taking the images.
- The whole area is covered by East-West-flight lines, which are divided in several sub-strips. Additional strips were flown along the valleys in lager scales. Thus a very inhomogeneous image pattern exists.
- Geometric problems appeared in some of the scanned images.

This paper presents the realisation of the automatic aerial triangulation using INPHO-software, the gained results and the corresponding quality control.

KURZFASSUNG:

Die *Autonome Provinz Bozen - Südtirol* beauftragte die Bietergemeinschaft *GEOSIGMA s.r.l.*, *GEOMATICA s.r.l.* und *Ingenieurgemeinschaft Vermessung AVT-ZT GesmbH* mit der Erstellung eines GIS-Datensatzes von Teilen der Provinz. Dabei sind Daten für eine technische Grundkarte in den Maßstäben 1:5.000 und 1:10.000 zu erstellen. Für die Datengewinnung war ein bereits vorhandener Bildflug mit rund 2.500 Luftbildern zu verwenden.
Nachfolgend werden jene Parameter angeführt, die die auszuführende Aerotriangulation besonders erschwerten:
- Alpines und topographisch sehr anspruchsvollem Gelände mit Höhendifferenzen von bis zu 2.000 m innerhalb eines Luftbildes.
- Die Befliegung erfolgte in einem Zeitraum von 4 Monaten. Dabei wurden 4 verschiede Luftbildkameras eingesetzt.
- Das gesamte Gebiet wurde mit West-Ost-Flugstreifen beflogen. Wegen der topographischen Gegebenheiten wurden die Flugstreifen in Teilstreifen unterteilt. Zusätzlich Streifen wurden entlang der Täler mit größerem Bildmaßstab erflogen. Damit ergibt sich eine sehr inhomogene Anordnung der Luftbilder.
- Bei einzelnen Bildern gab es geometrische Probleme in den Scandaten.

In diesem Beitrag wird über folgende Punkte bei der Durchführung der automatischen Aerotriangulation berichtet: Einsatz der dabei verwendeten Software der Firma INPHO, die erzielten Ergebnisse und die ausgeführten Qualitätskontrollen.

1. INTRODUCTION

By order of the *Provincia Autonoma di Bolzano – Alto Adige (PAB)* a GIS-dataset will be produced for the whole province *Alto Adige*. These data are used as digital technical base maps for the different governmental activities and duties, which were produced in 4 different map scales. The used scale depends on the economic and topographic situations within the area. The map scale 1: 5.000 is used for the settlement regions up to a height of about 1.500m above sea-level. For the rest of the province - these are wooded and mountain areas and pasture-land - the mapping scale 1:10.000 is used. The responsibility for these two map scales belong to the *PAB*. The scales of 1:1.000 and 1:2.000 are used for the centre-regions of cities and

villages. The responsibility of these data sets belongs to the community-government boards. The necessary object catalogues and instructions for the topographic data base exist. For data acquisition photogrammetric methods including additional terrestrial surveys as well as image recognition are used.

In summer 2002 the *PAB* was tendering the photogrammetric mapping and dataset production of the central region of the province with mapping scales 1:5.000 and 10.000. The bidding group *GEOSIGMA s.r.l.*, *GEOMATICA s.r.l.* and *Ingenieurgemeinschaft Vermessung AVT-ZT GesmbH (A.T.I.)* won this tender.

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The paper in question reports about Automatic Aerotriangulation (AAT) within this project which has been carried out by *Ingenieurgemeinschaft Vermessung AVT-ZT GesmbH (AVT)*. Existing standard knowledge and rules of the AAT cannot be transferred to this or similar projects. Hence, the most interesting and important results and solutions of the AAT are reported. It will be shown, that the AAT can successfully be used even in difficult applications such as the presented project.

2. PROJECT

2.1 Project area, Photo flight, Imagery

In Figure 1 the boarder lines between *PAB* and the neighbouring states as well as the other Italian provinces are documented. The actual project area - part 1 (= tessellated pattern) - is also visible. Its size is about 220 km².
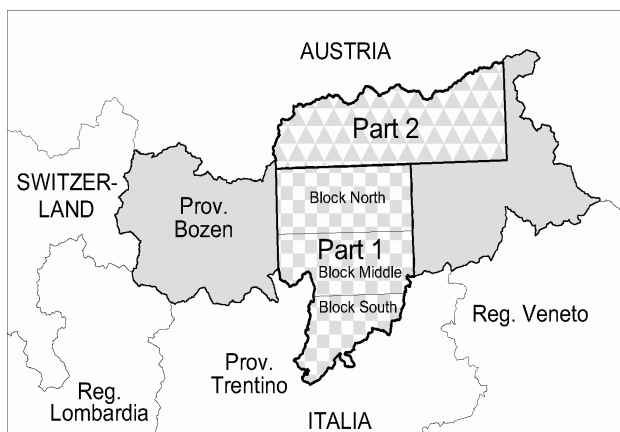

Figure 1. Map of the *Provincia Autonoma di Bolzano – Alto Adige* with their neighbouring countries, the project- and block borderlines

By order of the *PBA* the photo flight of part 1 and 2 where carried out by *Compagnia Generale Ripresearee S.p.A. (CGR)*. The flight of part 1 consists of 141 flights lines and 2557 images. It was carried out between July to October 2001. For this flight, colour negative film and two Wild RC 20 as well as two Wild RC 30 cameras (focal lens c=15 cm) were used. The directions of the flight lines were West East. The average photo scale is 1:13.000. The terrain heights in part 1 reach from 200 - 3.000 m above sea level.

Because of almost vertical rock walls (e.g. in the Dolomites) and the above mentioned within the project area, there are height differences of up to 2.000 m within one image. To get more constant image scales in spite of the mentioned topographic situations, the flight lines were broken into multiple parts with different flight heights. Additional flight lines were performed along the valleys. The average photo scales for these additional lines are between 1:8.000 – 12.000. Because of the described configuration, given conditions a very inhomogeneous image pattern resulted within the blocks. *CGR* delivered only approximations of the projection centres. The declared accuracy of these coordinates was between 0.4 – 1.0 m.

As already mentioned, the duration of four months had been necessary to complete the flight of part 1. Because of this long time interval the vegetation between neighbouring lines may differ. The mountains are responsible for large shadow parts within the images produced in September and October. These facts caused difficulties for the automatic matching process (e.g. Heipke and Eder, 1998). Similar problems existed for manual measuring of tie-points too.

CGR was scanning all images using a photogrammetric scanner ZEISS SCAI. The images where scanned with a 21 μm resolution. DVDs were used for data delivery.

2.2 Block division, Control and Check points

Smaller blocks have benefits concerning the photogrammetric work, the computing time for the adjustments and the error detection within the adjustment phase. In the project the GIS-data sets had to be delivered to a given schedule starting from south to north. Therefore the project area was divided into three blocks for the AAT– Block South, Block Middle and Block North. To achieve the required homogeneousness for the AAT results of the whole block an overlap of four flight lines between the adjacent sub blocks where used. The result of the block splitting of part 1 is shown in Figure 1.

The control points have been selected considering the above mentioned block splitting and the general rules for control points within aerotriangulation blocks (e.g. Kraus, 2003). Afterwards the required points were measured using GPS. The measurements were performed within the GPS-nets of the *Istituto Geografico Militare (I.G.M.)* – and the *Regione Trento – Alto Adige*. For this determination the given accuracy of the *PAB* had to be kept. Existing cadastre points were used as additional height control points within the aerotriangulation.

3. AEROTRIANGULATION

3.1 Aerotriangulation measurements

Measuring the interior orientation of the images, problems occurred. A data displacement occurred within some pictures. These errors were only detected because expected tie points were missing after the matching process between images of adjacent lines. Another problem was unexpected high residuals at the fiducal marks after carrying out the interior orientation of the images. After informing *CGR* about this problem, the images were scanned again. Getting back the new image data, the images were re-measured. However, the accuracy of the interior orientation of 171 images was still beyond the expected values. This problem existed within images taken with each of the four used cameras. The residuals were between 10 and 30 μm, as shown in Table 1.

Number of images	Residuals
1	> 30 μm (> 1,4 Pixel)
20	20 – 30 μm (1,0 – 1,4 Pixel)
26	15 – 20 μm (0,7 - 1,0 Pixel)
124	10 – 15 μm (0,5 - 0,7 Pixel)
171	Total number of images

Table 1. Residuals at the fiducal marks of problematic images

Because of legal conditions *AVT* could not get the original films. Therefore no investigations concerning the mentioned geometrical problems had been possible.

MATCH-AT permits sub-block handling with free block adjustment (see 3.3). To reduce the mentioned problems for the automatic tie point detection within the matching process, the following strategy was used:

1. Further splitting into sub-subblocks with similar image scales, same flight date and flight time.
2. Using a rough DTM and approximate values of the projection centres of each image (see 3.2) for the matching procedure.
3. Additional manual tie point measuring in problematic areas of neighbouring images to achieve a stronger connection.
4. Connecting sub-subblocks by manually tie point measuring.
5. Common adjustment of connected sub-subblocks.

3.2 Additional information for the block adjustment

As mentioned in 2.1 approximate coordinates for the projection centres were given. The flight company informed us, that the standard deviation of each coordinate is about 1.0 m.

As aforementioned, different photo scale, large height differences in the terrain, different texture because of changed vegetation within the images of neighbouring flight lines caused some problems for the matching procedure. This process can be improved by adding DTM-data. The "DEM 2000 – Digital Elevation Model" data with a grid interval of 100 m was used during the AAT. These data were submitted by the *PAB*.

3.3 Used AAT-Software

INPHO GmbH is offering two software tools for AAT - MATCH-AT and inBLOCK (Saile, 2003). *AVT* is using MATCH-AT, the automatic digital aerial triangulation software for the computation of bundle blocks. The main features of this adjustment software are:
- Support for all standard requirements such as processing of blocks of any size and any overlap
- Sub-block handling with free block adjustment
- Point selection, point transfer, measurement and block adjustment are integrated into one process without user interactions
- Automatic interior orientation
- Tie points are automatically selected in so-called 'tie point areas (v. Gruber)'
- The AAT procedure combines sophisticated image matching techniques with an integrated robust approach
- GPS and INS data handling
- Graphical representation of results and analysis support

Because of the very specific conditions of the presented project an independent review was done. The complete block was computed with the new bundle block software inBLOCK too. This software offers the following additional features:
- More flexible mathematical models are used for correction of systematic image effects. Available

models are 'Physical' (5 parameters), 'Brown' (16 parameters) and 'Ebner' (12 parameters).
- Complete statistical information:
  • Internal and external reliability values for all observations and unknowns.
  • Traditional values like residuals, RMS and standard deviations.

4. AAT RESULTS

This section describes the aerial triangulation results which have been gotten meanwhile. In Table 2 the a priori standard deviations are listed, which have been used for the bundle block adjustment with MATCH-AT and inBLOCK.

Full control points	X = Y = 0.05 [m]; Z= 0.07 [m]
Height control points	Z= 0.15 [m]
Projection centres	X = Y = Z = 1.00 [m]

Table 2. Used standard deviations (a priori) for the block adjustment (MATCH-AT and inBLOCK)

4.1 AAT results using MATCH-AT

Tables 3a – 3c show the AAT results of the three adjusted subblocks. The required accuracy for the aerial triangulation results and the succeeding photogrammetric restitutions in the scales 1:5.000 and 1:10000 are fully met!

Strips / images	59 / 949
Full control points	181
Height control points	70
RMS full control points	0.110/ 0.124/ 0.113 [m]
RMS height control points	0.188 [m]
RMS projection centres	1.342/ 0.277/ 0.433 [m]
RMS adjusted coordinates	0.065/ 0.071/ 0.162 [m]
Sigma 0	4.8 [μm]

Table 3a. Block South, results of the block adjustment

Strips / images	64 / 1009
Full control points	146
Height control points	106
RMS full control points	0.121/ 0.110/ 0.128 [m]
RMS height control points	0.236 [m]
RMS projection centres	1.014/ 0.226/ 0.395 [m]
RMS adjusted coordinates	0.068/ 0.077/ 0.160 [m]
Sigma 0	4.8 [μm]

Table 3b. Block Middle, results of the block adjustment

Strips / images	66 / 1213
Full control points	86
Height control points	44
RMS full control points	0.132/ 0.112/ 0.150 [m]
RMS height control points	0.361 [m]
RMS projection centres	1.153/ 0.212/ 0.245 [m]
RMS adjusted coordinates	0.053/ 0.060/ 0.132 [m]
Sigma 0	3.9 [μm]

Table 3c. Block North, results of the block adjustment

Additionally a thorough accuracy control for each block was carried out, which was done by using check points. The reference coordinates of these points were either terrestrial surveyed or taken from numerical photogrammetric mapping projects 1:1.000. These data were part of the data base projects for community-government boards (see 1.).

4.2 AAT results using inBLOCK

Table 4 shows the AAT results of the complete adjusted block.

Strips / images	144 / 2447
Full control points	259
Height control points	152
Sigma 0 – image	0.41 / 0.40 [μm]
Sigma 0 - full control points	0.136 / 0.138 / 0.156 [m]
Sigma 0 - height control points	0.182 [m]
RMS image points	2.895 / 3.345 [μm]
RMS control points	0.156/ 0.129/ 0.180 [m]

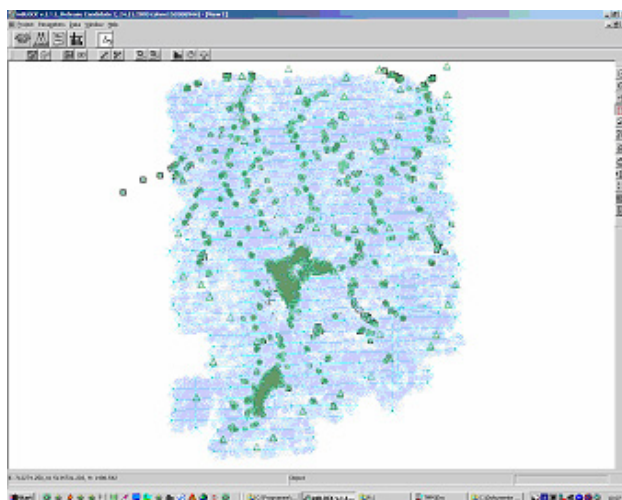Table 4. Complete block, results of block adjustment with inBLOCK

Figure 2. Overview of complete block with control points, new points and strips

For analysing the block lots of tools are available. One of those is the so-called blunder browser. The blunder browser is used to display information about possible blunders or eliminated blunders. The dialog consists of three parts: the numerical panel, the graphics panel and the control panel.

The numerical display shows the critical points (possible or eliminated blunders) with all observations. If there are blunders detected for position or attitude observations for projection centres, these are displayed as well. It shows the test values (normalised residuals) and estimated errors for the observations. The graphics display shows the estimated errors for the selected blunder in the numerical panel.

So the block can be checked very detailed. The weak areas of the block are found, checked and improved easily.

In inBLOCK all residuals and/or estimated errors of all points (control points, image points, GPS- or IMU-observations) can be displayed. For the current project no problems in the image

measurements were reported. The problems which had to be solved appeared in the control points. The GPS-data did not improve the result because the accuracy of 1m was too weak. So the control points were of particular importance. We checked the strength of the control points. Here the estimated errors in comparison to the residuals provide an informative basis. The estimated error shows the size of error the point could have without detecting it as 'blunder'.

Furthermore we checked the standard errors of the block. Here the error ellipses show the maximum error (calculated from the block geometry, number of measurements and the actual residual). The block had a homogeneous result, the error ellipses at the border are larger (2-fold points), the center of block showed only small error ellipses.

Also the **internal reliability** of the block was checked, which represents the size of a minimum detectable gross error for an individual observation. It can also be seen as a measure of the **controllability** of the observation.

External reliability is the influence of non-detectable gross errors onto the estimated parameters. It can also be seen as a **sensitivity measure** or robustness of the network against distorting effects in the system. Gross errors smaller than the threshold values (internal reliability figures) may stay undetected and contaminate the result. It is interesting to analyze the maximum influence of undetectable errors onto the estimates.

Inspecting the larger ellipses of the block showed that they are mainly caused by 2-fold points. These weaker points are checked by neighbouring points that had better analysis values. All information's such as coordinates, standard deviations, correlation matrix and outer reliability of the point can be displayed.

5. CONCLUSIONS

The adjustment results of MATCH-AT and inBLOCK gave similar results. The block was checked optimal by the analysing tools of both programs. To optimize the processing it would be preferable to use GPS-data in a higher accuracy (e.g. 0.10 – 0.15 m).

This report shows that using
- an appropriate software
- a correct pattern of control points within the block
- and the necessary Know how for carrying out such AAT projects

a high accuracy can be achieved even under difficult circumstances as given in the presented project.

Closing this paper it shall be mentioned, that the project of part 1 is finished meanwhile and that *Provincia Autonoma di Bolzano – Alto Adige* ordered the bidding group *GEOSIGMA s.r.l.*, *GEOMATICA s.r.l.* and *Ingenieurgemeinschaft Vermessung AVT-ZT GesmbH* to start with part 2 of this project (see Figure 1.).

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