OEEPE RESEARCH PROJECT AEROTRIANGULATION USING DIGITIZED IMAGES FINAL RESULTS

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ABSTRACT:

Aerial triangulation using digital imagery has been investigated as an OEEPE test using a large scale photography (1:4000) over a small town. The participants performed block triangulations using digital images of 15 µm and 30 µm pixel sizes and different methods and systems for measuring image coordinates. The adjusted ground coordinates were compared with geodetic coordinates. The results showed in comparison with accurate analogue methods the high potential of digital imagery in aerial triangulation.

1. INTRODUCTION

The development in computer science and technology as well as in photogrammetric research has gradually brought digital photogrammetry to a stage, where practical applications are becoming a reality. Especially such applications, which do not require complicated image understanding, are already possible. Aerial triangulation using digitized images (DAT) is one of these applications.

In aerial triangulation the digitalisation of the system brings several advantages:

- The image remains stable after the scanning process. Therefore no deformations can occur during the rest of the process. Also the use of orientation parameters in the mensuration phase is possible without any loss of accuracy.
- The high level of automation makes it possible to measure more points than in analogue systems. Therefore the effects of different image errors can be reduced. Gross errors can be detected more easily, systematic errors are better controlled, and the effects of random errors on adjusted values are smaller.
- Automation allows faster throughput and better economy.

Digital systems naturally have also some drawbacks, when compared to conventional technics. One of them is the loss of image quality due to digitizing. The resolution will be worse, and in the spectral range some errors can easily occur, even if the digital methods allow advanced image enhancements.

Only a few results from limited experimental tests on digital aerial triangulation has been available, so Commission A (Aerotriangulation) of the European Organisation for Experimental Photogrammetric Research (OEEPE) has organised a project, starting 1993, to bring more general knowledge about this area. The systems, which were available three years ago, were still mainly of an experimental nature. Therefore the scope of the test was limited to accuracy aspects of DAT. The operational side of the systems, very important itself, has been left out.

The purpose of the test was to get information about the potential of DAT and its special features, like the effects of pixel size, measuring resolution and method. The comparisons to conventional methods were also needed.

More complete results have been reported in the OEEPE official Publication No 31.

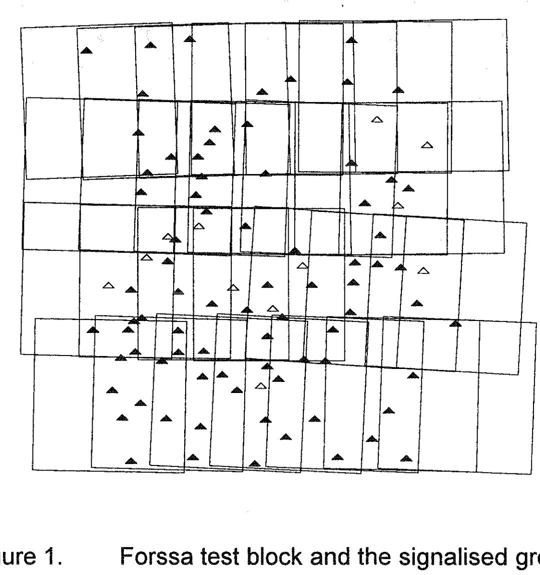

Figure 1. Forssa test block and the signalised ground points. Black triangles mean XYZ- and white triangles XY-points.

2. TEST AREA

Because of cost and time reasons, an old large scale (1:4000) photogrammetric block over the small Finnish town of Forssa was selected for the test. The photography had been made for practical mapping purposes in 1989, and has already been measured and adjusted with success. The total block consists of 60 images in 7 strips with 60 % side and end laps. Due to problems with a high amount of image data, a small subblock of 4 strips and 28 images (7 in each strip) was chosen for the test. The flight parameters are shown in Table 1, and the geometrical configuration of the block is presented in Figure 1.

Time of photography	3.5.1989 11:40
Flying height above ground	600 m
Scale of photography	1:4000
Camera	Wild RC 20/23
Principal distance	153.19 mm
Film	positive colour
Number of strips	4
Number of images/strip	7
End lap	60 %
Side lap	34 % (24% - 49%)

Table 1. Flight parameters of test block Forssa.

2.1 Ground points

The area was covered by a dense geodetic network, which was signalised using cross-shaped targets, the arms of which were 60 cm x 10 cm. Most of the points were measured using traverse measurements, and the coordinate accuracy of the signals was estimated to be below 15 mm in all three directions.

The control points for dense (14 XYZ-points) and for sparse (4 XYZ- and 4 Z-points) control, as well as the check points (50 XYZ- and 41 XY-points), were selected from this group.

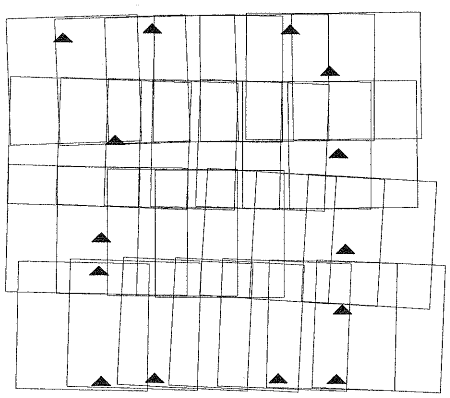

Figure 2 Control points in dense control configuration. All 14 points are XYZ-points.

2.2 Image material

The block was scanned in Landesvermessungsamt Baden-Württenberg in Stuttgart/ Germany using a Zeiss PS1 scanner in black-and-white mode with 15 µm pixel size. The scanning succeeded quite well except for some minor disturbances in image quality. Altogether, this very small block occupied almost 7 gigabytes demonstrating the problems of data storage. However, it was decided not to use any compression in this test, even if it seems to be a necessity in large blocks. Another image data set of 30 µm pixel size was created averaging every 2x2 pixel window.

3. TASK OF THE PARTICIPANTS

The task of the participants was to perform photogrammetric aerotriangulation with both data sets. The aim of the test was to investigate all varieties of the item, so there were no instructions concerning the measuring process. The choice of block adjustment software was also free. The blocks were adjusted using dense (14 XYZ) and sparse (4 XYZ and 4 Z) control as well as with and without additional parameters.

Some participants made the measurements using original film diapositives. Their results served as a comparison to contemporary photogrammetry.

4. MEASUREMENTS OF THE PARTICIPANTS

In all 13 participants, which have been listed below, have submitted results to the pilot center.

Agricultural University of Norway	Norway
École Polytechnique Fédérale de Lausanne	Switzerland
Eidgenössische Technische Hochschule	Switzerland
Finnish Geodetic Institute	Finland
Helsinki University of Technology	Finland
Institut Géographique National	France
Kungliga Tekniska Högskolan	Sweden
National Land Survey of Sweden	Sweden
Technical University Munich	Germany
Technische Universität Wien	Austria
Université Laval	Canada
University of Stuttgart	Germany
University of Trondheim	Norway

The participants made 155 different block adjustments. They were based on measurements, which can be divided into three main groups:

1. **Completely visual methods** (VM). Measurements are made on a screen in the same way as on an analytical plotter. They can be made in stereoscopic or monoscopic mode. When comparing to conventional methods, the advantages are the flexibility in treatment and display of images. The disadvantages are mainly related to a decrease in image quality.

2. **Semiautomatic methods** (SM). In this group automatic image matching has been used in some form in different tasks of image block measurement. The most common way is to match any kinds of homologous points on multiple images. Another automated task is the

measurement of fiducial marks and signals, mainly using template matching. Essential in this group is that the approximate values of points must be known in advance or gained using manual pointing.

3. **Automated methods** (AM). The basic difference, as compared to semiautomatic methods, is the automatic selection of tie points and acquisition of approximate image coordinates. In its most advanced form, the method is practically fully automatic. In the current status, at least the measurement of signalised points requires human interference.

In the following, the naming of the cases has been grouped according to the methods or measurements. Within the ranges, the cases usually differ in pixel size and type of block adjustment.

École Polytechnique Fédérale de Lausanne (EPFL)

The measurements have been made using Intergraph ImageStation and Leica DPW systems. Both are commercially available semi automatic systems. The measuring resolution of DPW system is one pixel. The adjustments have been made in all cases with additional parameters.

The BC1 and DSW100 (with DCCS software) measurements have been made for comparison.

EPFL 1 - 2 Wild BC1 analytical plotter measurements using analogue imagery. The cases have often been referred to with the name BC 1. (VM)

EPFL 3 - 4 Helava DSW 100 measurements. (SM)

EPFL 5 - 6 Leica DPW measurement. (SM)

EPFL 7 - 8 Intergraph ImageStation measurements. (SM)

EPFL 9 - 12 Adjustments with natural tie points.

Eidgenössische Technische Hochschule Zürich (ETH)

The measuring system was the selfdeveloped DIPS II. The semiautomated system includes also the automatic measurement of fiducial marks and signalised points using automatic template matching. (SM)

Finnish Geodetic Institute (FGI)

The used system was a selfdeveloped digital photogrammetric workstation, where automation was used in image matching. The matching is based on a cross-correlation method. The block was measured using different approaches:

1. Completely visual or semiautomatic measurements.

2. Different densities of tie points (17 - 34 points/image).

3. Different number of visual observations per signalised ground point.

4. Use of natural or signalised points as tie points

FGI 1 - 8 Visual observations. (VM)

FGI 9 - 16 Points were measured visually on the first images. On the following, correlated with the first observations. (SM)

FGI 17 - 24 Like FGI 9 - 16, but the tie points were natural details (no signals). (SM)

FGI 25 - 26 Like FGI 9 - 16, but all the points have been measured visually and then correlated to corresponding observations on other images. (SM)

FGI 27 - 34 Like FGI 9 - 16, but the number of tie points (natural) has been increased from 27 to 34 per image. (SM)

FGI 35 - 36 Like FGI 25 - 26, but using tie points like in FIG 27 - 34. (SM)

Helsinki University of Technology (HUT)

The experimental system was developed in the institute. For monoscopic visual measurements, variable measuring marks were available. The block adjustments were performed without additional parameters. (SM)

Institut Géographique National (IGN)

The 15 μm data was measured using a selfdeveloped system on a Vaxstation (IGN 1 - 4) (SM). The 30 μm data was measured on a Matra Traster T10 (IGN 5 - 8). (VM)

Kungliga Tekniska Högskolan (KTH)

Measurements were made completely visually using ERDAS software (KTH 1 - 4) (VM) and semiautomatically using a system developed in the institute (KTH 5 - 9) (SM). The semiautomatic system includes template matching on fiducial marks and signals.

Agricultural University of Norway (NLH)

The measurements were made visually using ERDAS OrthoMAX block triangulation software. The measurements were made without stereoscopic viewing and area based image matching, even if they were included in the system. (VM)

National Land Survey of Sweden (NLSS)

Measurements were made visually on Teragon system. (VM)

University of Trondheim (NTH)

The measuring system was ERDAS with the remote sensing module. (VM)

Technical University Munich (TUM)

The measurements were made using an experimental system. The observations were made visually with two measuring resolutions, 1 pixel (TUM 1 - 4) and 1/3 pixel (TUM 5 - 8). One control point in dense configuration was not measured, which makes the comparison to other measurements slightly biased. (VM)

University of Stuttgart (TUS)

The measurements on digital imagery were made using visual and automated methods. In the automated measurements, the special features were automatic selection of tie points, feature based matching and high number of tie points. A basic difference, as compared to other methods, is also the way tie points are used. The points are in small patches, which correspond to single points in the other methods. Very typically, the points were measured on only two images.

The Zeiss PK1 measurements were made in a conventional way for comparison.

TUS 1 - 4	Zeiss PK1 monocomparator measurements using analogue imagery. The cases have often been referred to with the name PK1. (VM)
TUS 5 - 12	Visual observations on digital images. (VM)
TUS 13 - 16	Automatic measurements using 15 μm data (272 points per image). (AM)
TUS 17 - 20	Automatic measurements using 30 μm data (237 points per image). (AM)
TUS 21 - 24	Automatic measurements using 30 μm data (131 points per image). (AM)

Technische Universität Wien (TUW)

The method is based on feature based matching, but, in this case, unlike TUS, the number of points corresponds to conventional cases. (SM)

Université Laval (UL)

The measurements were made completely visually using Leica DVP system. The measuring resolution of 1/2 pixel is lower than in most systems. (VM)

5. ANALYSIS OF THE RESULTS

The analysis of accuracy is based on three methods;

- Calculation of root mean square error values (RMS) from differences between known and adjusted check point coordinates.
- Calculation of RMS values from short horizontal distances of neighbouring traverse points.
- Theoretical error estimates delivered by the block adjustments.

Most of the analysed cases are based on dense control and additional parameters.

5.1 15 μm pixel imagery

The results with 15 μm pixel size, dense control, and additional parameters are presented in Figure 3.

In plane coordinates, the RMS values, the variations of which are relatively small, are around 20 mm. An explanation for bigger values in TUM 2 is the one pixel measuring resolution, and in TUW 2 the low number of points when using feature based matching.

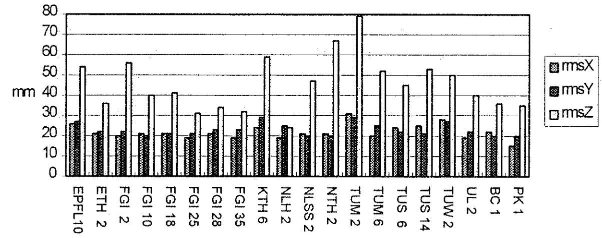

Figure 3. RMS values from 15 μm pixel size data, as well as from BC1 and PK1 measurements when using dense control and additional parameters.

In comparison to measurements using analogue imagery, the best results are at the same level with the BC1 measurements, and only slightly worse than the PK1 results. The used block with signalised check points is favourable for visual methods, in general, and especially for monocomparator measurements.

In a comparison between the different measurements of a single participant, no big differences can be found. An increase of measuring efforts, like in the series of FGI, seems to have no influence in planimetric accuracy.

In the Z-coordinate, the variation is larger. The largest errors have often occurred, when using visual methods (FGI 2, NLSS 2, NTH 2, TUM 2, TUM 6, TUS 6 and UL 2). An exception from this is NLH 2.

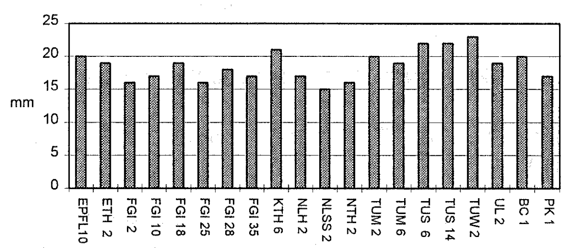

Figure 4. Estimated local coordinate errors calculated from short distances, when 15 μm imagery, dense control, and additional parameters have been used.

The coordinate accuracies calculated from short distances (Figure 4) show that the pointing accuracy on check points has varied. These values have an effect on values in Figure 3.

5.2 30 μm pixel imagery

The results from 30 μm data with dense control and additional parameters (Figure 5) have somehow a different nature than the corresponding results using 15 μm data. The variations of RMS values between different cases are, in general, larger, and the height-to-planimetri-accuracy relation is in most cases clearly smaller.

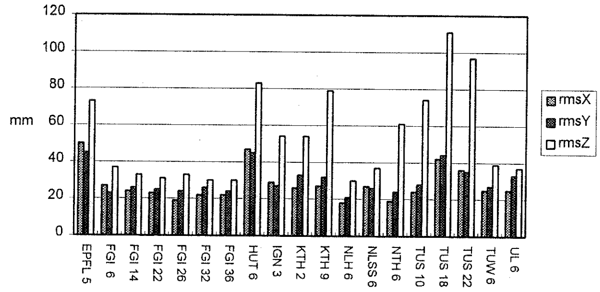

Figure 5. RMS values from 30 µm pixel size data when using dense control and additional parameters.

The importance of the quality of observations comes out from cases TUS 18 and 22. TUS 22 (131 points/image), a subset of TUS 18 (237 points/image), included only the 20 best tie points per image patch in the block adjustment. In spite of much higher number of observations, the accuracy is in TUS 22 better than in TUS 18.

An anomaly, which can be explained in these results, is the case EPFL 5. Here the reason was found to be the measuring resolution of 1 pixel.

5.3 Effect of pixel size

The effect of pixel size has been investigated by comparing corresponding adjustments with both pixel sizes. Figure 6 shows that 30 µm imagery produces, in plane, slightly less accurate (10-20%) results. There is a remarkable difference in TUS 14. The reason is the feature based matching method used, the accuracy of which is tied to pixel size.

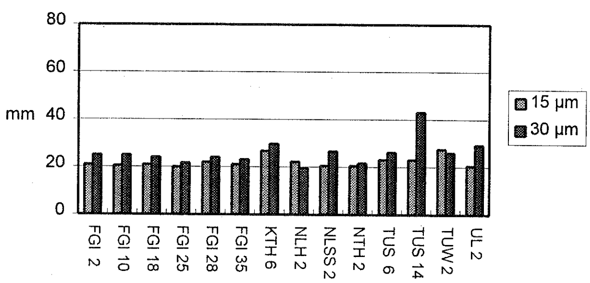

Figure 6. The RMS values of plane coordinates from adjustments with 15 and 30 µm data when using dense control and additional parameters. The names refer to cases with 15 µm data.

In height accuracy the results are unexpected (Figure 7). In most of the cases the heights are more accurate when using 30 µm data. This is true for visual methods as well as for systems using accurate image matching methods. An explanation for this could be the fact that with the larger pixel size the area used for matching (also in visual cases) is larger on the ground. So, the texture on the background of the signals is better, and the matching on a flat surface brings more precise parallaxes.

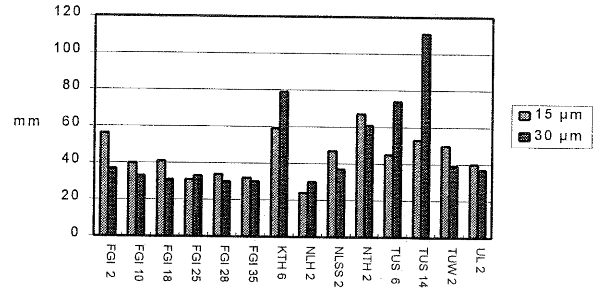

Figure 7. The RMS values of height coordinates from adjustments with 15 and 30 µm data when using dense control and additional parameters. The names refer to cases with 15 µm data.

5.4 Effect of measuring resolution

The effect of low resolution can be regarded as a rounding-off error, the mean error of which is 0.29 of the measuring unit. In case of 1/2 pixel resolution and 15 µm pixel size, it causes an additional random error of 2,2 µm into the measured coordinates.

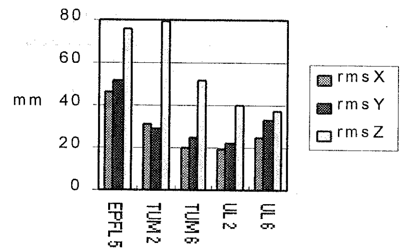

Figure 8. Results from measurements with low resolution (1 - 1/3 pixel) when using dense control and additional parameters. EPFL 5 = 30 µm / 1 pixel, TUM 2 = 15 µm / 1 pixel, TUM 6 = 15 µm / 1/3 pixel, UL 2 = 15 µm / 1/2 pixel and UL 6 = 30 µm / 1/2 pixel.

The measurements with lower resolution (1 - 1/3 pixel) are, in the case of dense control and additional parameters, presented in Figure 8. In TUM 6 and UL 2 the accuracy is at the same level as in most other cases with 15 µm data. With 30 µm pixel size, a 1/2 pixel resolution, corresponding to a 4,4 µm random error, has already a greater effect on the adjusted coordinates. This can be seen in UL 6. Figure 6 also shows that the decrease in plane accuracy from UL 2 to UL 6 is larger than in the other comparable cases. One pixel resolution with 30 µm data leads already to remarkable errors (EPFL 5 and TUM 2).

It can be concluded that, in aerial triangulation, the measuring resolution must be better than 10 µm, and in the most accurate cases below 5 µm. These values are still high, when compared with conventional photogrammetric systems.

5.5 Effect of tie point type

In the block a large number of tie points (in some cases > 60 %) were signalised check points. To investigate the behaviour of the block when only natural tie points are used, additional measurements and calculations were made in EPFL and FGI. In EPFL new block adjustments were made so that all the check points were excluded, leading at the same time to lower redundancy. In FIG all the check point measurements in cases FIG 10-17 were replaced by new measurements on natural points in the vicinity of each check point, preserving the geometry of the block. Check point coordinates were then calculated after the block adjustments using spatial intersection.

The results of plane coordinates are presented in Figure 9. They show that in digital systems natural tie points are as good as signalised points. The conclusion is the same with Z-coordinate.

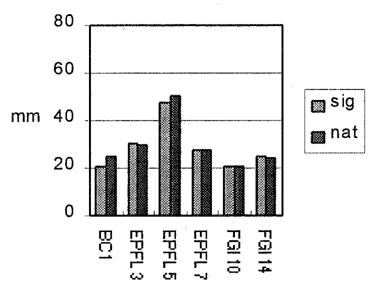

Figure 9. RMS values of plane coordinates in measurements of EPFL and FGI, when all possible (i.e. signalised and natural = sig) and only natural (nat) tie points have been used. The blocks have been adjusted using dense control and additional parameters.

5.6 Theoretical accuracy estimates

The accuracy of check point measurements on the images has direct influence on the accuracy estimates of ground points. To avoid this problem, also theoretical estimates, calculated in the block adjustments, were analysed. However, the analysis of the estimates of the elements of exterior orientation showed that these values alone do not give any reliable information for comparisons. The large differences in block geometry were the main reason.

6. CONCLUSIONS

This project on digital aerial triangulation was implemented as a multi-site comparative test project. Nearly all of the triangulations carried out by the participants would satisfy normal requirements of any mapping or data collection project. This is a very positive outcome, especially when the large variety of the methods and systems and also the experimental nature of these systems is taken into account. The main results of this test project are related to accuracy. The following detailed conclusions can be made:

- Digital aerial imagery seems to have the potential for accurate aerotriangulation. In the best realisations, the accuracy is at the same level with the most accurate conventional methods. With the proper usage of automation, which means a high amount of tie points, high quality coordinate measurements on the image, an even distribution of tie points, and good ties between image strips, the accuracy potential of digital imagery exceeds that of analogue data and conventional methods.
- In this test, pixel size was, in most of the cases, a less important factor than expected. It was in the most accurate methods, almost neglectable. On the other hand, pixel size is, in systems using feature based matching for tie point measurements, the most critical factor.
- A measuring resolution of half a pixel is sufficient also with small amounts of observations, if the pixel size is 15 μm.
- In methods using area based matching, signalised tie points are not significantly better than natural details.
- Planimetric accuracy is in completely visual methods using digital imagery, in the best cases, at the same level with more advanced methods. The heights are in most cases slightly poorer.
- The relation of height to plane accuracy is smaller when area based image matching has been used on tie point measurements than in visual methods.
- The used theoretical accuracy estimates give too large values for height accuracy. The reason is the incorrect stochastic model used in block adjustments.
- Sensitiveness to sparse ground control is, when using digital methods, very often larger than with conventional analogue methods.

The conclusions above have been drawn from the results and experience obtained in this case. It is especially characterized by the use of large scale photography in urban area. The results could be different in other conditions and with different project parameters. The most important parameters are the scale of the photography, the block size, the shape and size of the signals, and the use of in-flight GPS measurements. In these respects, there are many opportunities for further development and research.

References from Other Literature:

Jaakkola,J., Sarjakoski,T. 1996. Experimental Test on Digital Aerial Triangulation. OEEPE Official Publication No 31.