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Operational Use and Empirical Results of Automatic Aerial Triangulation

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ABSTRACT

Aerial triangulation isn't only a major photogrammetric task but it also provides the exterior orientation for aerial photographs. Therefore it is generally required for the most other photogrammetric tasks. In the last time the automation of aerial triangulation with the help of digital techniques has reached an operational level. This paper describes a software system for automatic aerial triangulation. Pilot projects of conventional photogrammetric blocks and digital imagery from 3-line CCD cameras are already processed with this software.

1. INTRODUCTION

The aerial triangulation usually consists of two phases, the phase of mensuration (including preparation and point transfer and point identification as needed) and the phase of block adjustment. Whilst the block adjustment, since many years, is to a great extent an automated process, the automation of the mensuration phase was only possible with the development of digital photogrammetry. Digital image matching techniques open new possibilities for the complete automation of the point transfer and measurment and consequently the aerial triangulation.
At present there are two strategy lines in practical use, which can be pursued in digital aerial triangulation. The first strategy uses semi-automatic methods and is close to the conventional procedure of analytical photogrammetry. The human operator selects interactively one or several suitable tie-points in an image and gives the approximate location of its homologous points in the other images. Then the image point is transferred automatically by image matching (commonly least squares matching). This strategy offers a solution for point transfer in a digital workstation but it doesn't exhaust the possibilities of digital photogrammetry. The second strategy, which is pursued here, goes one essential step further and attempts a fully automated procedure for selecting, transfering (matching) and measuring tie-points. In this case not only the selection of tie-points is automatic but the approximations are obtained automatically too. The operator only has to give the initial approximations (block-configuration, forward- and side-overlap) and control the results. Interactive guidance and interference is necessary only in critical cases. Under this point of view a system for automatic aerotriangulation has been developed at Stuttgart University (Tsingas, 1992). Additional development and implementation has made the system ready for operational use. Since last year there exists a special version of the program for the processing of digital images of 3-line CCD cameras (MOMS02, DPA) (Fritsch 1995).

2. THE CONCEPT FOR AUTOMATIC AERIAL TRIANGULATION

The main specifications of the system's concept are automation and subpixel accuracy. The system is supposed to work only with cross initial approximations. They are the block-structure (strips, images) and the forward and side overlap. The approximate values for the point selection and transfer can be obtained automatically using an image pyramid. To reach the accuracy level of analytical aerial triangulation the image coordinates must be assessed to subpixel accuracy. The method must be fast enough to operate with many more tie-points as by conventional methods (usually more than 100 per image). Such strong ties imply high redundancy with all its advantages concerning easy and safe blunder detection and high accuracy of the resulting exterior orientation parameters. Therefore the system is modular programmed and easy to improve and to extend. The system consists of a method

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for the automatic selection and transfer of tie-points, i.e an image matching method, and of a strategy for the automatic operation of this method through the vertical structure of the image pyramid and the horizontal overlap structure of the photogrammetric block.
A method for automatic point transfer must solve the problem of various and multiple overlap, which is appearing with photogrammetric blocks. While the mono- or stereovision systems of conventional photogrammetry limit the point determination to one or two photographs, the use of digital methods allows processing of all overlapping photographs simultaneously. Therefore multiple image matching is the general approach for point determination in digital photogrammetry. From the two main directions in image matching area-based methods are potentially highly accurate but they need very good approximate values. On the other hand feature-based matching is less accurate than area-based matching but its subpixel accuracy is sufficient for many applications. Feature based matching requires only coarse initial approximate values and is very fast which means it is more suitable for automatic processing. Therefore a method of multiple feature image matching was developed, which is based on a graph theoretical model (Tsingas, 1994). The method provides pixel coordinates of multiple tie-points automatically selected and matched. The method operates with many more tie-points than are conventionally used in aerial triangulation. If a higher accuraccy is needed, the pixel coordinates of the homologoues image points can be used as approximate values for a least square matching (a software module will soon be developed). The above elementary method operate with overlapping image patches. A major problem in image matching is the provision of sufficently close approximations. In order to solve that problem automatically the system goes step by step through an image pyramid.

3. OPERATIONAL STEPS

3.1 Data Acquisition and Preparation

Whilst digital sensors (for example the 3-line CCD camera) supply digital data directly, the photographs must be digitized with a pixel size from 10-30 μm in the case of conventional photogrammetric blocks. Once the images are in digital format an image pyramid has to be generated. The data storage and eventually the data transfer are at present quite critical because of the amount of the data, the costs for digitization and storage as well as the time needed for it. This situation will be changed soon because the development in the area of storage and sensor technology is very rapid (increasing performance and storage capacity by decreasing prices).

3.2 Measuring of Fiducial Marks and Control Points

The pixel coordinates of the fiducial marks are needed to transform the pixel coordinates of the image points to image coordinate system. For this purpose a software module is used, which displays an image (including its image pyramid) on the computer screen and allows the positioning, with subpixel accuraccy, of a measuring mark (circle or cross) with the mouse (Fig. 1). The same module is used to measure the control points. The sytem displays the image overview (left window in Fig. 1) and the interesting image area in two diferent resolusions (middle and low pyramid-level). With three mouse-clicks the operator can approximately locate the control point. Afterwards the point is measured with subpixel accuraccy (top-right image window in Fig. 1). This method provides sufficient accuracy and is very fast (less than 1 min. per point or fiducial mark). A bundle adjustment of the block FORSSA (see chapter 4.1) using signalized tie-points, which were measured with this method, gave similar results (σ_o = 3.9 μm) with the corresponding analytical measurment on the Zeiss PK1 monocomparator (σ_o = 3.5 μm). It is planned to integrate a template matching module in the future . The measurement of the control points before the point transfer is useful for the determination of the block structure in the next step.

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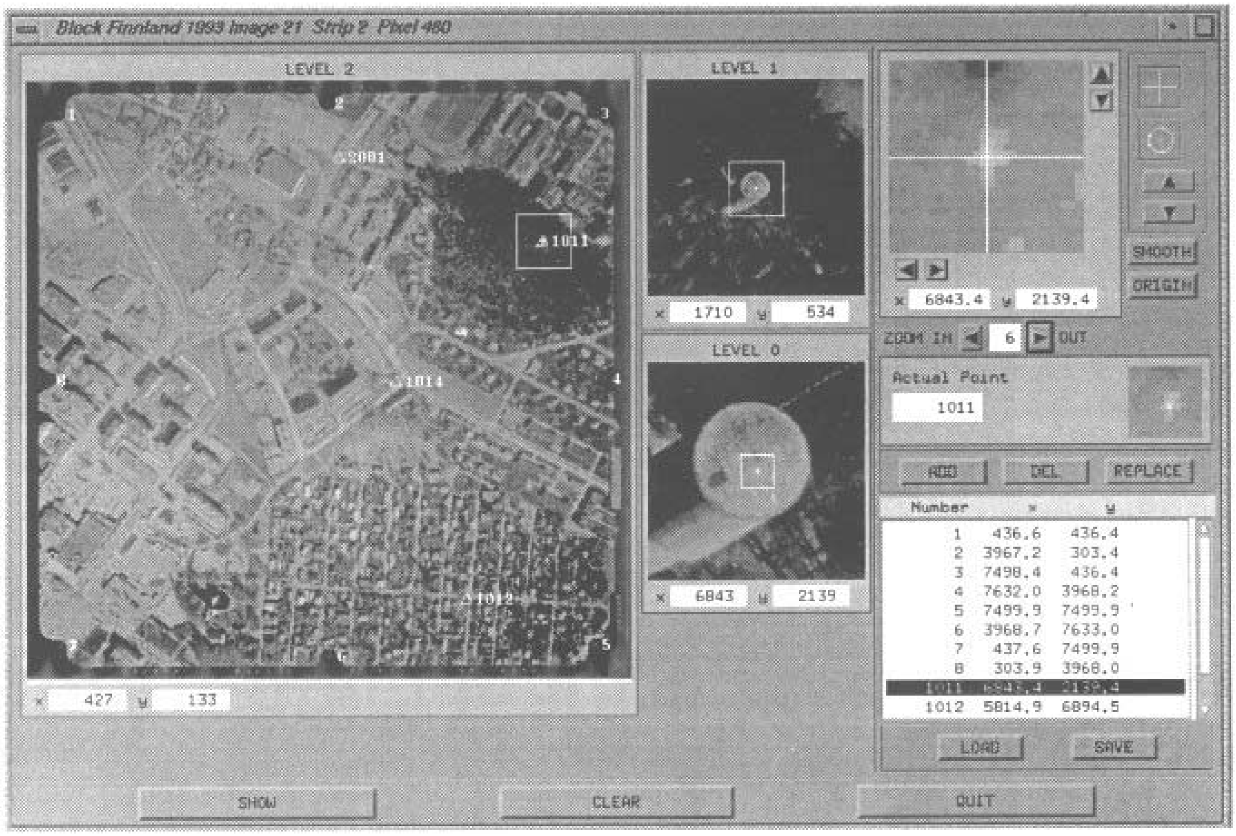

Figure 1: Software module for interactive measurement of fiducial marks and control points.

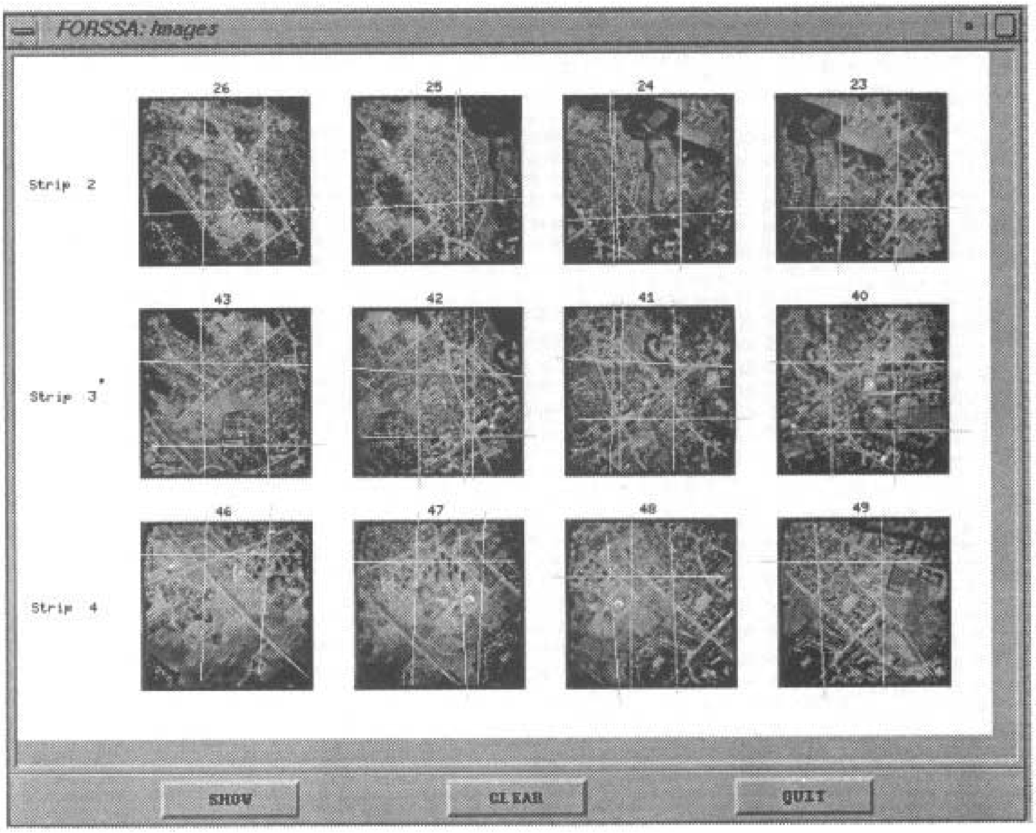

Figure 2: Automatically determined overlap between neighbouring image pairs.

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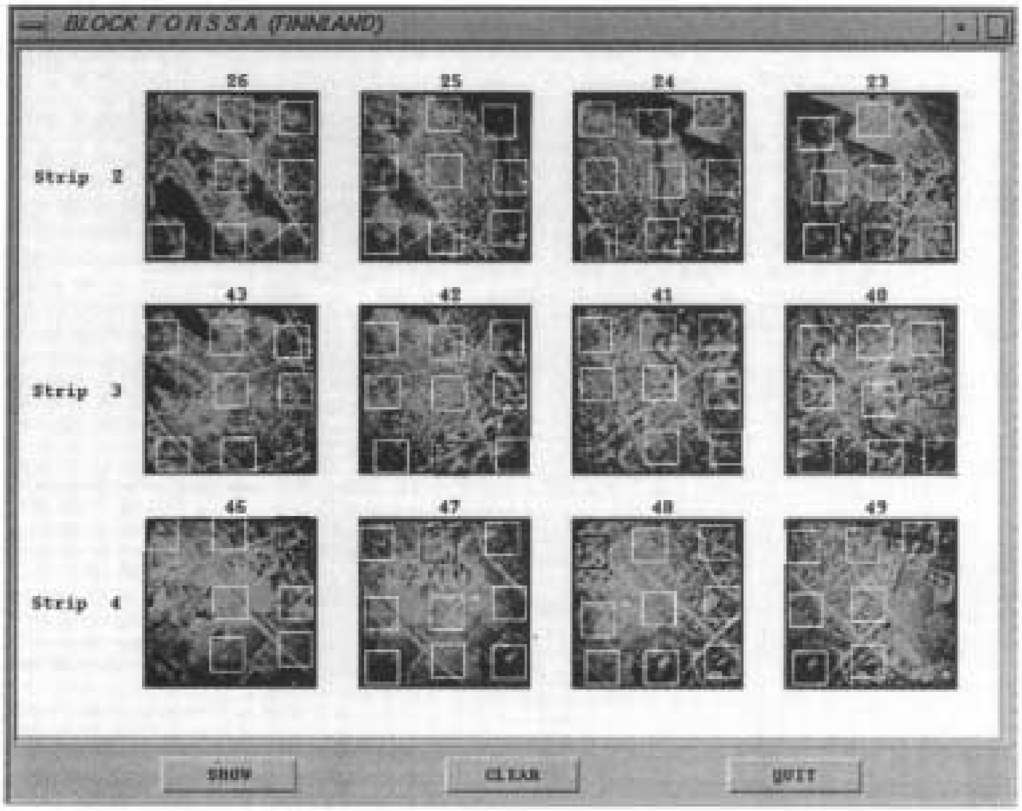

Figure 3: Initial image patches for point transfer (top level).

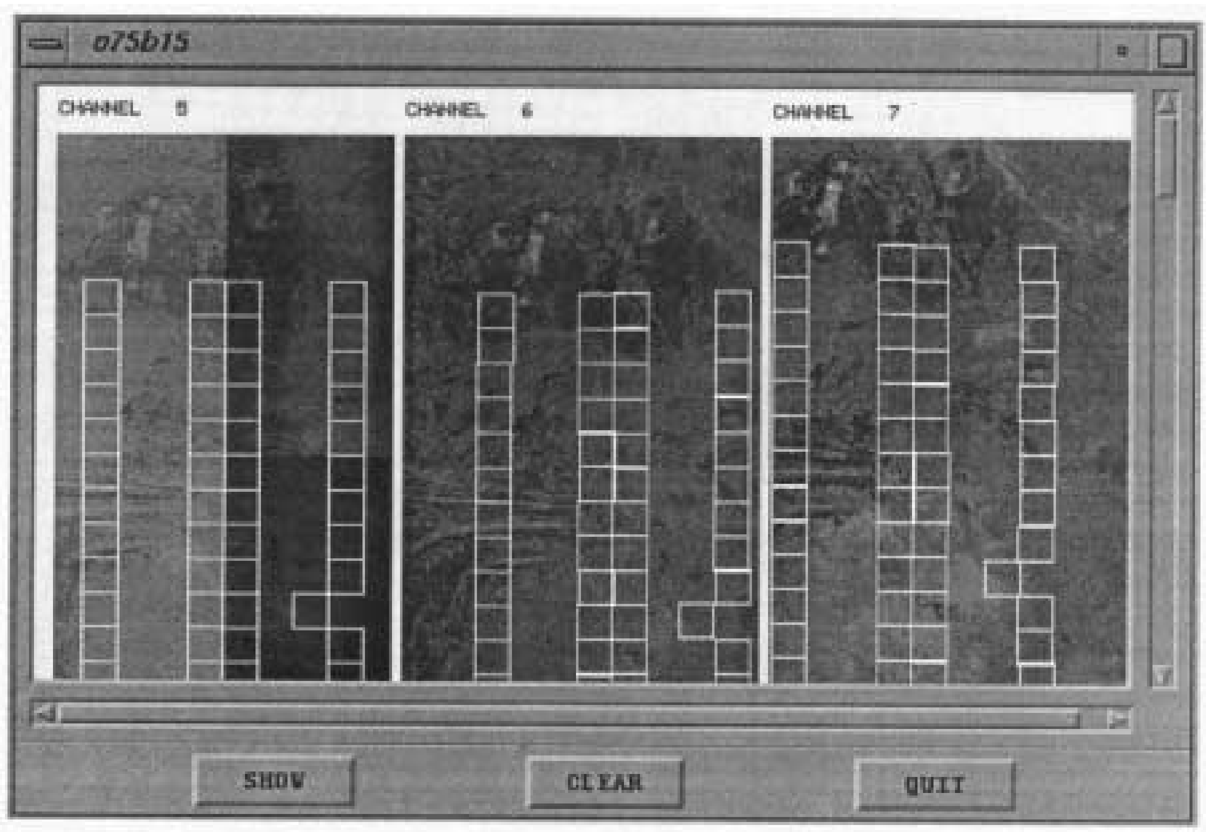

Figure 4: Image patches for point transfer in case of MOMS02-data (mid level).

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3.3 Determining the Initial Approximate Values

In case of photogrammetric blocks the program needs only the block structure as pre-information (strips and images sequence, forward and side overlap in precent). A coarse level of the image pyramid (980 µm pixel size) is used for the automatic identification of the forward and side overlap. The overlap of each imediadiately neighbouring image pair (for example the image pairs [i,i+1] and [i+1,i+2]) is determined with the matching procedure more accurate (1mm). This method works good if the overlap is more than 30%, otherwise an interactive guidance is needed in critical cases. The overlap of the other conjugate image pairs (for example the image pair [i,i+2]) is computed with the help of the already determined overlap of the above image pairs. Figure 2 shows an overview of the block FORSSA. The lines on each image represent the transformed border of the neighboring images. Therefore the block is subdivided in areas with various overlap. The initial image patches are positioned in these areas. In the case of conventional aerial triangulation the initial image patches are normally located near the 9 standard position within an image at which the tie-points are ideally positioned (Fig. 3), but also irregular overlaps can be accomodated. For images with three-line geometry more tie-points are required, which must lie at the marginal and center zone of the image. Therefore the initial patches are placed respectively (Fig. 4).

3.4 Digital Point Transfer

An image pyramid of three levels, separated by a scale factor of about 4 or 5, is sufficient to provide close approximations. Once the initial homologous image patches heve been identified the actual process of the image point selection and multiple matching of tie-points will start on the top level of the image pyramid. This process is subsequently repeated by the remaining two levels of the image pyramid. Any selected point serves as an approximate center for defining the respective image patch on the next lower level on which again the method is applied. With regard to the number of selected points per patch different strategies can be pursued. In the minimum case only one point is selected and transferred onto the next lower level of the image pyramid. A safer strategy is to transfer two or more points (Table 1, Pyramid strategy). The program has an interactive modus, which allows to visualize the matching results for each step (Fig. 5).

3.5 Data Reduction and Bundle Adjustment

Once all measurement are finished the pixel coordinates of the tie- and control-points have to be tranformed to the image coordinate system. After that the image coordinates can be used for a bundle adjustment program. With the digital point transfer and measurement the complete aerial triangulation takes place on a computer and no special hardware is needed. Therefore the bundle adjustment can be used during the measurement-phase to locate gross errors and to improve the approximate values. This option is more useful in case of 3-line image geometry, where each image row has a separate exterior orientation.

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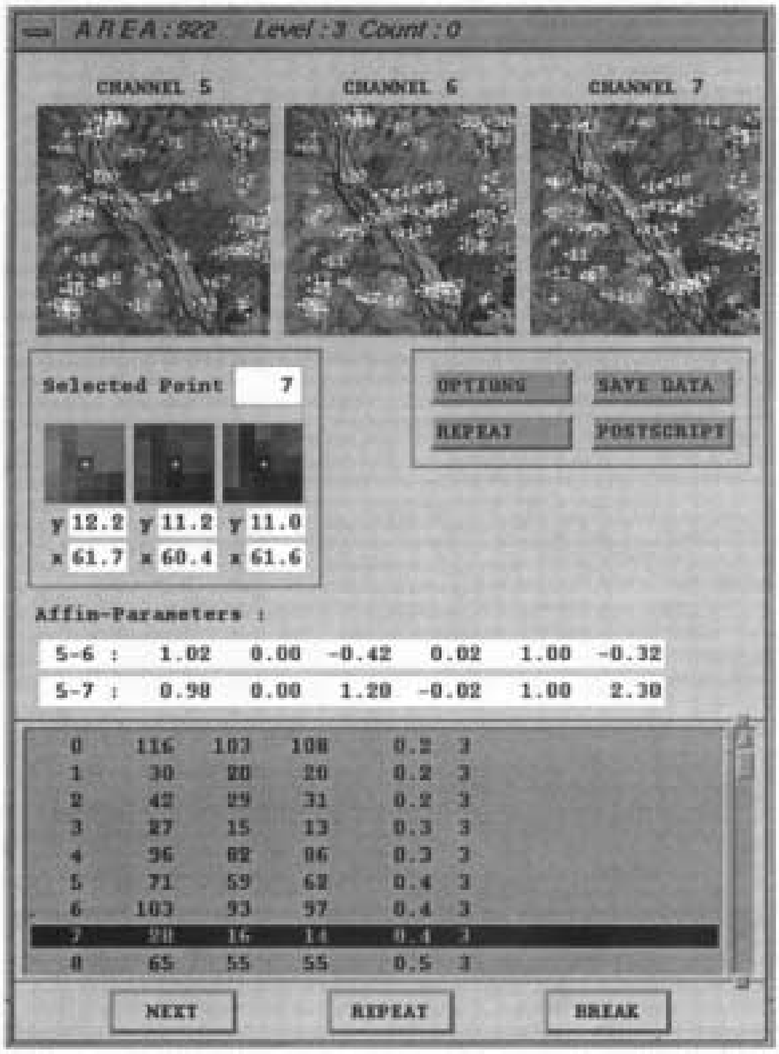

Figure 5: Graphical visualisation of the matchings results.

4. EMPIRICAL RESULTS

4.1 The OEEPE test Block FORSSA

Last year the Institute for Photogrammetry of Stuttgart University has participated in the OEEPE test "Digital Methods in the Aerial Triangulation". The OEEPE block FORSSA comprised 28 aerial photographs, in the scale of 1:4000, forming a block of 4 strips with 60%-70% forward and 15%-40% side overlap. There were 2 data sets of digitized images with 15 µm and 30 µm pixel size respectively. For comparative purposes a conventional analytical aerotriangulation was made with signalized tie-points. The results of the aerotriangulation and the bundle-adjustment (14 XYZ control points, without self-calibration) are shown in Table 1 and they are discussed in detail in Ackermann and Tsingas (1994). The latest results from other blocks will be presented during the photogrammetric week.
Interactive support of the automatic process was required in 6% of all image patches.The support was limited to interactive provision of the approximate values. The problem areas are related mostly to the small side overlap between the strips. Other problem areas can be forests or built-up areas with large perspective distortion, especially in large scale aerial images. The number of issued tie-points was quite large, amounting to 272 image tie-points per image (15 µm data). 6% of the delivered image points were discarded as small outliers in the final adjustment. This rate of errors seems quite acceptable, as the high redundancy permits safe and complete detection. With the 30 µm data the rate of outliers is

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reduced to 0.7% by 131 points per image. The program needs 31 min (1.1 min per image) on a Silicon Graphics Workstation (Processor R4400 / 200 MHz), refering to 7643 image tie-points and the safer patch strategy. By applying the minimal patch strategy (30 µm data) the processing time is reduced to 11 min (0.4 min per image).

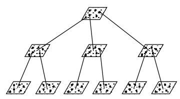
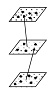
DIGITAL AERIAL TRIANGULATION - OEEPE TEST BLOCK FORSSA			
	Analytical	**Digital - Automatic**	
Pixel size	-	15 µm	30 µm
Pyramid strategy	-	safe 	minimal 
Overlap areas Interactive support (approx. values)	- -	780 6%	234 6%
Points per patch	-	10 best	20 best
Image points (per image) Terrain points Outliers in adj.	492 (17) 151 -	7623 (272) 3401 6%	3686 (131) 1526 0.7%
processing time per image	(6 min)	1.1 min	0.4 min
σ_o [µm] ([pixel])	3.5 (-)	6.2 (0.41)	10.6 (0.35)
Empirical Accuracy (RMS) resulting from 81 XY and 71 Z check points			
μ_X [cm] μ_Y [cm] μ_Z [cm]	2.4 2.7 4.9	3.6 3.9 5.3	4.3 5.1 8.1
Theoretical Accuracy of orientation parameters (RMS)			
σ_ω [mgon] σ_φ [mgon] σ_k [mgon] σ_{Xo} [cm] σ_{Yo} [cm] σ_{Zo} [cm]	4.1 4.1 1.5 4.4 4.7 2.6	3.3 2.7 1.0 3.0 3.7 2.5	6.6 5.7 2.1 6.2 7.3 4.4

Table 1: Results of conventional and automatic aerial triangulation.

Looking at the accuracy results the major item of interest concerns the σ_o. In first instance it concerns the precision of the feature extraction and the feature matching. In other words, it describes the image coordinate precision of the automatic digital procedure and can be compared with the conventional values obtained by traditional point marking and point transfer, resp., as well as with the precision of signalized triangulation points. The σ_o of the digital aerial triangulation amounted to 6.2 µm (0.4 pixel) for the 15 µm data and 10.6 µm (0.35 pixel) for the 30 µm data. This result is close to the theoretical precision of feature extraction (0.3 pixel). The theoretical accuracy of the exterior orientation parameters was clearly better, than the accuracy obtained with the conventional analytical block triangulation because of the high redundancy.

4.2 Automatic Point Transfer with 3-line Imagery (MOMS-02/D2)

Since last year the above method is used for automatic point transfer of MOMS-02 image data. Because of the 3-line geometry about 12000 tie-points per image (32000 x 2900 pixel) are needed for a reliable determination of the sensor orientation. Three orbits (Libya 75, Australia 75b and Andes-Bolivia 115) were processed with the modified program (Fritsch, Schneider, Tsingas, 1994). The middle net processing time for the matching procedure (3-fold image window with 80x80 pixel) is 0.2 sec. In this time more than 50 points are transferred to the other images. In figure 3 the graphical visualisation of the matching results is shown. To process an orbit the elementary procedure must be called 2050 times giving a total processing time of 7 min. The bundle-adjustment gave an image coordinate precision (σ_o) of 0.6-0.7 pixel with an outliers' rate of 1%. These results are very promising with respect to the image texture and the ground surface (desert in Libya and Australia, mountains and jungle in Bolivia).

5. CONCLUSION

Generally, it can be concluded that the digital aerial triangulation gave very good accuracy results, which qualify the method as a high precision aerial triangulation. Summarizing the empirical tests it can be stated that the results are extremely promising in every respect. The above software system has reached an operational level which allows the fast and reliable point transfer with data of conventional photogrammetric blocks and 3-line imagery. Future developements aim to increase the reliability of the system, to minimize the interactive support and to integrate software modules for least squares matching and bundle adjustment. Automatic digital aerial triangulation will not only be more accurate than comparable conventional aerial triangulation but is supposed to be very fast and less expensive.

6. REFERENCES

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