'Photogrammetric Week '95', D. Fritsch & D. Hobbie, Eds., Wichmann Verlag, Heidelberg, 1995

Introduction into Digital Aerotriangulation

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ABSTRACT

Aerotriangulation has reached a main breakthrough in the sixties and seventies when adjustment techniques solved the spatial resection problem of photogrammetry. Nowadays, digital photogrammetric workstations offer a further giant step aiming at fully automated aerial triangulation.
This paper introduces with the typical workflow in photogrammetric aerotriangulation. Using digital photogrammetric workstations as platform interactive and automated procedures are reviewed. The conclusions offer future scenarios in photogrammetric point identification and point transfer.

1. INTRODUCTION

Aerial triangulation (AT) is a complex photogrammetric production line which starts directly after the analogue (aerial) images are developed and ready for measurement purposes. In a broader view AT includes also the photo flight planning, the photo flight itself, and the use of GPS positioning. The main tasks to be carried out are the identification of tie points and ground control points, the transfer of these points in homologous image segments and the measurement of its image coordinates. Lastly, the image-to-object space transform is performed by bundle block adjustment.
With the development of digital photogrammetric workstations - sometimes called softcopy workstations - and high resolution image scanners, which both are offered at a highly operational level, aerial triangulation should be automated. The analogue images are scanned and stored on hard disks to start the photogrammetric production line in this entirely digital environment. It seems today, that the robust tool of bundle block adjustment can highly be integrated in new strategies with a high degree of automation.
First investigations to automate aerial triangulation has been started by V. Tsingas (1991, 1992). The main bottleneck to be overcome is point transfer and the measurement of image coordinates of tie points. These operations are carried out in practice entirely by a human operator. Tsingas has shown, that digital image matching methods can be applied to solve the automated identification of tie points and to derive their image coordinates, if corresponding homologous image patches are found by a graph theoretic approach. The application of his strategy on the OEEPE FORSSA block has proven the high potential in accuracy and automation of digital aerial triangulation (F. Ackermann/V. Tsingas, 1994).
In the meantime further strategies are proposed and are under development. T. Schenk/C. Toth (1993) have worked out a comprehensive and most sophisticated concept - it is under development as indicated by C. Toth (1994). The suggested approach uses an integrated matching concept including point and edge feature matching for robust initialization. The first objective is met by generating a block system which consist of a DEM of the project area, the exterior orientation parameters of all images and their footprints. After the block system is generated a multiimage matching procedure starts (T. Schenk, 1995).
Using also a DEM in the automatic aerial triangulation is suggested by F. Ackermann (1995). It is assumed that all digital images of a block are given, arranged in image pyramids. It is further assumed that all ground control points have been measured interactively, on the highest level of pixel resolution. The proposed system applies feature detection and feature matching, working for the time being on a symbolic image description. For the whole block, potential tie points are defined using the Förstner operator, what is done in all overlap combinations. The identification of mismatches and of good

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matches is carried out by bundle block adjustment, which uses all available information, besides the image coordinates of tie points and ground control points also high precision camera positions. This approach runs through the image pyramid.
Future investigations will show that automatic production lines for aerial triangulation are more efficient than interactive ones. For the time being, the photogrammetric workstations offered on the market are not yet prepared. But sooner or later digital aerotriangulation is a product of the same value as the automatic generation of digital elevation models.

2. PHOTOGRAMMETRIC WORKFLOW IN DIGITAL AEROTRIANGULATION

The workflow of digital aerotriangulation mainly depends on the strategy being used. It is out of question that the identification of tie points and the measurement of its image coordinates could be done manually on a digital photogrammetric workstation. The same holds for the measurement of ground control points. But the benefit working in a digital environment is its automation potential. Therefore, manual work should only be concentrated on tasks for which automated strategies are not yet feasible. As far as digital aerotriangulation is concerned this is restricted only to the identification of ground control points and signalized tie points, as well as the measurement of image coordinates of these classes of points.
The difficulty of detecting (signalized) ground control points when working in a digital image of reasonable resolution - let us assume 15 - 30µm pixel size - is the pixel width of the point signal. In order to be reliable more than 3-5 pixel should be used in any template matching process, otherwise the matching algorithm is not able to match the template with its image. One solution to overcome this problem would be a pointwise improved resolution of the scanning process, what means the scanner should automatically driven to points with signals. As a consequence the scanning software should include already template matching algorithms to be autonomous in this respect. However, there are some open questions on the implementation of such intelligent strategies. The normal approach therefore refers to the manual measurement of the ground control points and signalized tie points.

2.1 Interactive versus automated point transfer

The task of digital aerotriangulation is the complete process of aerial triangulation including block adjustment, on the basis of digital imagery resp. scanned analogue images by semi- and/or fully automated procedures. One essential sub-task is the selection, transfer and measurement of image tie points by digital image matching. The real challenge is the realization of a high degree of automation using a structure, which allows the integration of bundle block adjustment procedures without any loss of information and efficiency. As it is known, automation is to be classified in semi-automated systems and fully automated systems. Semi-automation is mostly the first goal, because the human operator could intervene the process at any time. But as far as aerotriangulation is concerned, the fully automated system should be preferred.

2.2 Interactive point transfer

In order to transfer points of overlapping regions standard positions of point transfer have to fixed at first. This results into the well-known 9 positions, which are also used in manual daily work. The number of overlapping regions of the same area is restricted to the forward and side lap of the image flight - the point transfer itself can be automated in the way that the human operator defines the tie point in one image (master) which is transferred in all other homologous image patches afterwards automatically.

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In figure 1 it is symbolically shown how the point transfer will take place. The matching process itself is an image-to-image matching by feature based and/or intensity based matching. This figure indicates a simultaneous solution for 6 images.

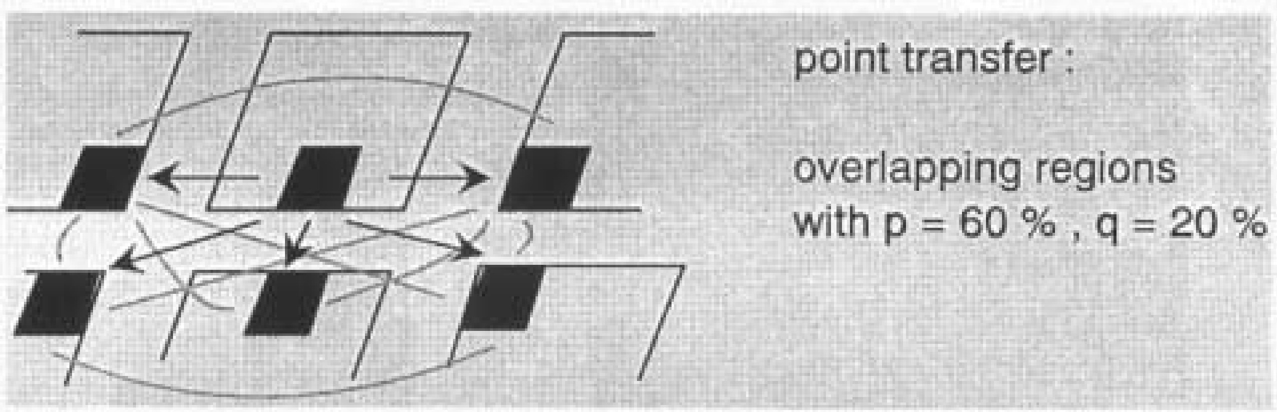

Figure 1: Selection of standard positions for point transfer.

In figure 2 an extract of intensity based matching for point transfer is presented. Two levels of the image pyramid are shown. The interactive point transfer is started by the operator; he clicks the mouse onto the region where the point should be transferred from the master image in the slave images. A search window of 61x61 pixel is shown on the left hand side, from which the matching window of 31x31 pixel is extracted. For both windows a margin of 5 pixel is presumed - therefore the intensity based matching uses a window of 21x21 pixel. The upper two windows represent the level 2 of the image pyramid, the lower ones level 0, which is the original image. The strategy to solve the multiimage matching problem can be started using pairwise image matching. All the matched images are transformed back into the master image to prove the success of the matching. In this way the number of matching processes becomes $\binom{n}{2}$. This approach was successfully applied to transfer MOMS02/D2 images. It has the advantage of being simple with the subpixel accuracy of intensity based matching. Altogether 6 parameters of an affine transform are determined and additionally 2 parameters for radiometry. It is also known that the approximate values for least squares image matching should be in the range of 2-3 pixel.

2.3 Automated point transfer

As stated in the introduction three main strategies can be differentiated up to now. The approach developed by V. Tsingas uses the featured based matching in three levels of an image pyramid. The feature extraction and multiple feature matching is solved in four main steps:

1. Feature extraction in every digital image
2. Preliminary pairwise image matching by computing the correlation coefficients
3. Localization and elimination of gross errors by means of an affine transform
4. Multiple image matching of incidence matrices in a graph-theoretical model

The feature extraction delivers image coordinates with subpixel accuracy of about 0.3-0.4 pixel. Within the list of possible candidates it is searched for homologous points on the basis of an affine transform, which is well suited as functional model for all possible image pairs. After the elimination of gross errors there might exist matching errors of smaller scale as well as ambiguities. This is to be overcome using the graph-theoretical model. The deviation of a pair of points from the functional model is introduced as weight of an edge of a planar graph. The multiple image matching forms a complete sub-

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graph, also called clique. A remaining task consists of finding the maximum sub-graph with minimum edge weights. This is overcome by binary programming.

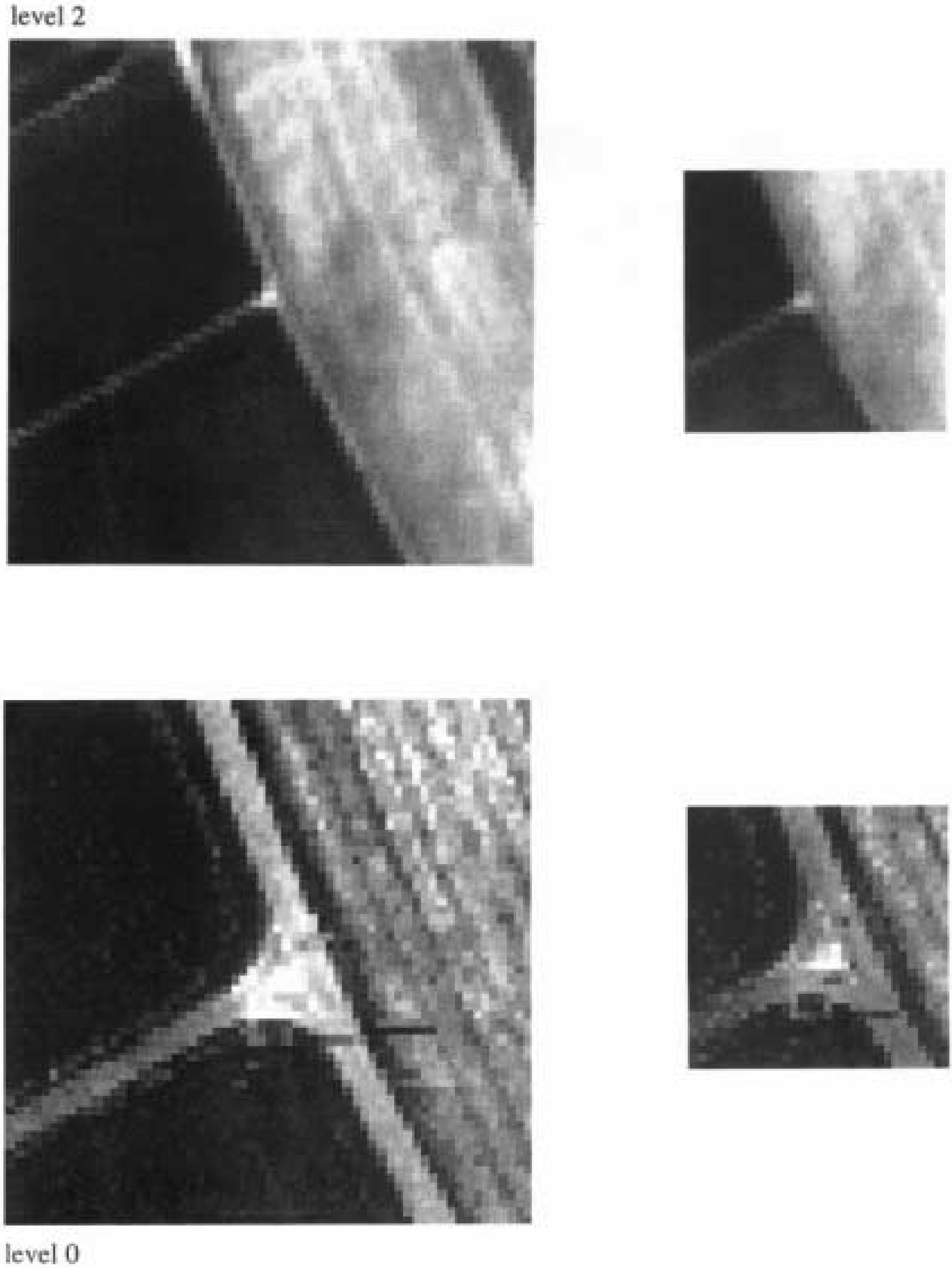

Figure 2: Point transfer in two levels of an image pyramid.

Currently, the Institute of Photogrammetry, University of Stuttgart is investigating other solution strategies to solve the multiple matching problem. Besides an integration of intensity based matching other efficient methods are under consideration. Practical experience is given with the approach above, therefore this will be demonstrated in the following two examples.

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3. EXAMPLES

The potential of digital aerial triangulation is demonstrated using two examples: one example worked out for aerial photographs and another one using three-line imagery of the MOMS02 sensor. The first one is directly convertible with every days photogrammetric work done in practice - the latter is up to now investigated only on a scientific basis. For both applications soon it became clear that digital aerial triangulation is powerful and with regard to the MOMS02/D2 data the only way to solve the restitution problem.

3.1 The FORSSA Block

DIGITAL AERIAL TRIANGULATION - OEEPE BLOCK FORSSA							
pixel size		15 µm [0]		30 µm (case A[1])		30 µm (case B[2])	
no. image points (per photo)		7643 (272)		6641 (237)		3686 (131)	
no. terrain points		3403		2991		1526	
no. outliers in adj. (image points)		6%		1.6%		0.7%	
ground control points		14 XY 14 Z	4 XY 8 Z	14 XY 14 Z	4 XY 8 Z	14 XY 14 Z	4 XY 8 Z
σ_0	[µm]	6.2	6.2	11.8	11.7	10.7	10.7
	[pixel]	0.41	0.41	0.39	0.39	0.36	0.36
Empirical Accuracy							
number of check points		81 XY 71 Z	90 XY 76 Z	81 XY 71 Z	90 XY 76 Z	81 XY 71 Z	90 XY 76 Z
RMS	μ_x[cm]	3.6	4.2	5.0	6.5	4.3	5.7
	μ_y[cm]	3.9	5.1	5.5	8.0	5.1	7.3
	μ_z[cm]	5.3	7.1	9.4	11.5	8.1	9.2
Theoretical Accuracy							
block points RMS	σ_x[cm]	2.5	3.0	4.6	5.5	4.2	5.2
	σ_y[cm]	2.7	3.4	4.9	6.3	4.4	5.9
	σ_z[cm]	5.9	6.3	10.8	11.5	9.9	10.7
orientation parameters RMS	σ_ω[mgon]	3.3	4.0	6.6	8.2	6.6	8.1
	σ_φ[mgon]	2.7	2.8	5.4	5.7	5.7	6.1
	σ_κ[mgon]	1.0	1.3	2.0	2.5	2.1	2.6
	σ_{X_0} [cm]	3.0	3.6	5.9	7.0	6.2	7.3
	σ_{Y_0} [cm]	3.7	5.3	7.4	10.6	7.3	10.5
	σ_{Z_0} [cm]	2.5	3.0	4.6	5.7	4.4	5.6

[0] 6 patches per overlap area, 10 best points per patch
[1] 1 patch per overlap area, all points of patch
[2] 1 patch per overlap area, 20 best points per patch

Table 1: Digital Aerial Triangulation - OEEPE Block FORSSA.

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The Institute of Photogrammetry, University of Stuttgart participated in the first comprehensive test on digital aerial triangulation announced by OEEPE under the supervision of the Finnish Geodetic Institute,Helsinki, Finland. The analogue images were scanned at the Landesvermessungsamt, Baden-Württemberg with the high resolution image scanner PS1 at a resolution level of 15µm. Three runs were made with the automated point transfer and its corresponding graph theoretical approach developed by V. Tsingas. The results in table 1 are taken from F. Ackermann, V. Tsingas (1994).
As indicated by table 1 the σ_o of the bundle block adjustment corresponds with 6.2mm resp. 0.41 pixel (the values at the highest resolution) to the same level as reached by manual measurements of image coordinates. Using a more precise matching technique, for instance to start at the feature points an intensity based matching these results can be considerably improved. The main point at this stage is not the accuracy itself but the savings in time effort. The results above have been derived on a Silicon Graphics IRIS Indigo Workstation (MIPS 3000 processor, 33 MHz, 32 MB RAM), for which 5.3 min were predicted per image. (All in all 28 images were processed automatically). Recent repetition of the experiment on a Silicon Graphics Indigo2 Workstation (MIPS 4400, 200 MHz) resulted in an accelerating factor of at least four - this means about only 1min for an image.

3.2 Automated point transfer of MOMS02/D2 images

The processing of digital three-line imagery could not be done without any automatic point transfer opportunity. Therefore, a strategy has been developed taken into account the weak geometry of the three-line perspective. The kernel of the resulting software package consists of feature based matching of tie points identified by the Förstner operator in independent homologous image patches. The mismatches and good matches are found by an affine transformation - the strategy runs through an image pyramid of three levels. Altogether the algorithmic chain of the digital aerotriangulation can be described as follows:

1. Preparation of the image data (level 1): tiling, datum transform (if necessary)
2. Feature extraction in every of the three MOMS panchromatic channels
3. Preliminary pairwise matching using feature similarity in every homologous image pair (image patch)
4. Detection and elimination of outliers using an affine transform
5. Determination of multiple matches using a graph-theoretical model
6. Bundle block adjustment (using an extended functional model)

The software package developed at the Institute of Photogrammetry, University of Stuttgart, needs for the automatic measurement of the image coordinates in all three panchromatic channels simultaneously about 6ms (on a Silicon Graphics Indigo2, R4000/200 MHz). In order to have an overview on the number of points to be transferred, it is referred here to the scene 75b/17 (Australia), for which more than 70.000 tie points were transferred. A manual measurement is therefore impossible. The final accuracy reached by the bundle block adjustment amounts to 0.7 pixel using feature based matching - a refinement of the matching process by intensity based matching could improve this figure to 0.3 pixel. Although these numbers are below the expectations, the high cartographic potential of the MOMS02 sensor could be proven.

4. CONCLUSIONS

It was made clear that digital aerial triangulation is no longer a time-consuming photogrammetric production line, but a task which can totally be automated. The implementation on a digital photogrammetric workstation is not restricted using stereo - it should run on any powerful graphic

workstation, mostly as batch job. Before the process is started only the control points have to be identified and measured manually. This problem is still under investigation, probably ground control chips (GCCs) may overcome the remaining manual work. These chips are stored in data bases to be used in template matching.
A GCC is an image and/or vectorial description of a natural or man-made well-identified point (GCP), line (GCL) or area (GCB). Using GCCs the absolute orientation step should be more simplified and also automated. The template retrieved from the data base is used as window to be matched with the images of the block. Using further knowledge on the distribution of the GCPs - for instance a GPS block may be restricted to have only ground control in its corners - a search strategy accelerates the matching process. This matching process should be carried out on the iconic level, what means intensity based matching is presumed. The resulting accuracy of the automated measurement of the image coordinates should then be 0.1 pixel or even better.
The progress in automated aerial triangulation interferes also other non-conventional measurement techniques of photogrammetry. With the development of airborne laser scanners the resulting DTM strips have to be merged to DTM blocks. This mapping problem can also be overcome using strategies of digital aerial triangulation. Using 3D feature operators tie points are identified - the correspondence of homologous tie points in overlapping strips is found using intensity based image matching. The height values represent virtual grey values which are then matched by affine transformations.
The last question in this context is the following: Is aerial triangulation still up-to-date? The answer is very simple:Yes. There is no other surveying method available which delivers for instance attitude information of such high accuracy. But this is only a by-product of aerial triangulation. Digital aerial triangulation is a very precise, robust and efficient tool of photogrammetry to determine a large cluster of point coordinates on the Earth' surface. If it is automated then it should not avoid any comparison on costs with further point determination techniques.

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