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Practical Experience with Digital Aerotriangulation

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ABSTRACT

The revolutionary development of electronic computers from the mid-60-ies onward, allowed the development of powerful programs for the computation of aerotriangulations (AT). Since the end of the 80-ies the further explosion in computer-speed and storage-capacity opened up the posibility of Digital Photogrammetry. Some 2000 modells have been processed on the Digital Scanning Workstation **HELAVA DSW 100**. For some 40 models, a direct comparison of digital aerotriangulation (DAT) with an analytical AT was possible. The results and some limitations of DAT are discussed. There is a substantial time-saving factor and also a noticible gain in accuracy.

1. INTRODUCTION

The principal ideas and geometrical and mathematical solutions for **picture-or-photo-triangulation** are known since the last two decades of the last century, and new solutions to apply these principal ideas to the new media **aerial photography**, which was becoming available at the turn of the century and specially during the later years of the first world war, followed soon. The earliest mentioning of the expression of **aerotiangulation**, which I could trace down, was a paper by S. Finsterwalder in 1921. At the same year there is also a report of the same author in the **proceedings of the mathematical-physical section of the Bavarian academy of sciencies** on **radial triangulation**, a method which later became kown as **slotted templets**. The main incentive originated from the idea of bridging distances, where ground-control was not available, or very difficult and time-consuming and thus expensive to obtain. During the following 20 to 30 years very intensive research was carried out to improve the results of these early ATs. They were connected with names like **Kuny, Schermerhorn, R. Finsterwalder, Nowatzky, Gotthardt,** to name just a few. All these activities at their time had one dominant idea in common: **to avoid calculations as much as possible**.

This is very understandable as the only calculation capacities at that period was limited to the performance of mechanical calculators, such as Brunswiga, Thales, Olivetti, or Curta. This initated the development and perfection of the **analog stereo-plotters** such as the Stereoplanigraph C-8 by Zeiss, the Stereoautographs A-5/6/7/8 and 9 by Wild, various types of Stereotopographs of Poivilliers, plotters of Nistri and Santoni, the Stereometer of Drobyscheff, or the Stereoprojector of Romanowski, all avoiding calculations as much as possible and actually acting as **analog computers.**

With these instruments substantial improvements in the photogrammetric procedures were reached, but for ATs the results were still not so convincing and satisfying.

The turn of the tide started in the late 50-ies, and gathered real momentum after the mid-60-ies when fast and powerful electronic computers became available, which permitted the development of complex and powerful computer-programs to handle the enormous volume of the calculations of an AT. The next steps foreward were the introduction of the **analytical plotters** in the late 70-ies and finally the gigantic explosion of computer capacitiy, capability and speed from the second half of the 80-ies onward, when Megabyte-memories were no longer prohibitively expensive exeptions and even Gigabyte-memories were becoming available at very reasonable prices. From the mid-60-ies onward powerfull programs for ATs such as PAT-M and PAT-B from Ackermann of the TU of Stuttgart, the programs of the ITC of Delft, Bingo of the TU of Vienna, ALBANY and BLUH, to name just a few, were becoming available and from the early-80-ies on ATs performed on analytical plotters were rapidly becoming standart photogrammetric procedures. With these new capabilities digital photogrammetry also approached a stage of practicability and by 1992 some 3 or 5 digital workstations of different makes were presented to the users.

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With the introduction of the analytical plotters, such as the Planicomp series of Zeiss, or the AC-1 or BC-2 of Wild, the AT-procedures have reached the present perfection and status. For example with 4500-scale aerial photography of a 15/23 camera, an accuracy in m_x / m_y of ± 2 cm and m_z of ± 3 cm, which corresponds to 4 and 6 µm in the picture-scale respectively, can be reached on points, carefully signalized on the ground. The last draw-back of the **analytical solution** was the still necessary marking of tie points - **pugging** - on the original picture-material using some point-transfer-device such as the PUG of Wild. The development of digital stereo- or mono-plotters and the use of **automatic or computer-aided picture-correlation** software such as **DCCS** of Helava did overcome this last obstacle.

2. THE DIGITAL PLOTTERS

Digital plotters no longer use original photographs, but scanned - **digitized = digital** - information of photographs or other imagery. This means that a huge quantity of data, even for the present standart of computer-technology, has to be handled in near real-time. Depending on pixle-size one wants to use, a normal aerial photograph of 23 cm square, requires still a very respectable storage-space. In our case on the **Helava DSW 100** we have installed the pixle-sizes of 7.5 µm and 20 µm. One complete photograph scanned with 20 µm would give some 130 million pixels and use about 80 Mbyte of the storage capacity of the hard disc drive of the host computer. The smaller pixel-size would increase this figures to 940 million pixels or 580 Mbyte respectively.
Carrying out digital photogrammetric procedures requires a very powerful computer for the very complex arithmetical processes which can handle and manipulate picture-coordinates of the just mentioned volume in near real-time.

3. THE HELEVA DIGITAL SCANNING WORKSTATION DSW-100

The **DSW-100** is a computer-controlled precision photogrammetric instrument. It opens the posibility to handle ATs with digital data, thus moving away from the actual photograph to scanned digital information, originating from aerial photography or other imagery.
It consists of four main-groups:

1) Photogrammetric stage,
2) Operation controller unit,
3) Host computer,
4) Workstation console.

Group 1 consists of a **high-precision scanner**, with **two CCD sensor cameras and linear encoders** for very precise positioning. The picture is placed on the 270 x 270 mm² glass-plate of the picture carrier, where an area of 254 x 254 mm² can be scanned. The motions of the picture carrier are performed on an high precision perpendicular X-Y axis rail-assembly, actuated by computer-controlled DC servo motors. The scanning is done by one of the two CCD sensor cameras, which is switched on for the particular job. A resolution of 1 µm in positioning and a maximum speed in picture movement of some 30 mm/sec is reached. The photo is illuminated through an Ulbricht-sphere, which is situated on the top of the stage housing. It gives a very uniform light, within 1% deviation from the full illumination-power, over the entire opening of the illuminated area. The light travels through a fiber optic cable from a quartz halogen lamp, which is placed lower down in the stage housing, thus avoiding heating up of the picture carrier. The two CCD cameras are mounted with 135 and 105 mm lenses. Other lenses are optional. The pixel size can be varied from 7 µm to 100 µm depending on the optical adjustment. To limit the data-volume to be handled during the AT, the scanned area for each

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point to be measured, is reduced to a size of 6x6 mm². This patch can be zoomed up to double size for better vision.
Group 2 consists of one monitor, a X-Y data tablet with mouse, with which the operator can control the AT-procedures and the movements of the picture-carrier, and of a second high-resolution monitor, where the scanned patches can be displayed and viewed at.

Figure 1: The Heleva Digital Scanning Workstation DSW-100.

Group 3 consists of the **Host-computer,** which is in our case a Compaq 486, 66 Mhz, 32-bit, 32 Mbyte RAM, 256 Kbyte cache memory, with Unix operating system and with a 1.7 Gbyte hard disc drive. It serves all movement-controlls, handles the scanning operation and data-storing and also houses the **Digital Correlator Comparator System (DCCS)** Software modul, which performs the actual measurement by **automatic picture-correlation.**
Group 4 consists of tables on which the other units can be arranged.

4. PROCESS OF DIGITAL AEROTRIANGULATION (DAT)

4.1 Preparation

The selection of tie points can be carried out on mere paperprints and they can be marked just with pen or ink-circles etc. The transfer of these points to adjacent prints of the same or the next strip can be done with mere eye and hand accuracy, at most a pocket- or mirror steroscope may be used. The latter might be a good help altogether for choosing points. No PUG or other point-transfer-device is needed. Care has to be taken only, that a particular point may not be obscured by some objects on one of the adjacent pictures.

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4.2 Measurement of the aerotriangulation

Only picture-coordinates are measured in a picture coordinate-system which is referrenced by the fiducial marks of the individual picture. The actual measurement is done automatically with the **Digital Correlation Comparator System (DCCS) program-modul.**

The first photograph (original negative or diapositive) of the particular project is placed on the picture carrier plate and a paper print of the same photograph is oriented on the X-Y tablet of the control system. The DCCS program automatically drives to the first fiducial mark and the operator has to pin-point the measuring mark in the center and record that point. The same procedure is repeated with the other fiducial points. With the last fiducial point measured, the interior orientation is completed. Then the operator will clip on the selected points on the X-Y tablet. The DCCS progam will direct the picture carrier to the corresponding point. The final selection of the very point is again done with the measuring mark and when accepted by the operator, the point is finally recorded and a patch of some 6 x 6 mm^2 is scanned and stored in the host-computer memory. The same procedure is done with all points, tie points, control points and additional points, which might be recorded, even if they were not selected before, during the preparation. With the second picture the same procedure is performed until the end of the interior orintation. Then the first tie point is clipped on with the mouse on the X-Y tablet, the picture carrier is automatically moved to this point and if this patch is sufficiently matching with the patch recorded in the first picture, the point is automatically correlated and thus measured and stored in the memory of the host-computer. The same procedure is carried out with the second point. After that, the second picture is oriented by the DCCS program and all previously scanned points from the first or previous pictures are automatically driven to, correlated and recorded. The operator just has to accept the correlation and then the DSW 100 moves on to the next point. In case of a bad match the operator can manually perform the correlation, or if that is not possible he may reject this point completely and replace it by an other newly selected point. This procedure continues till all previously recorded points are measured. Then the new tie points, or other points which shall be included in the AT, are chosen as in the first picture. This pattern is repeated until the end of the project.

The measured picture coordinates are further processed using one of the existing AT programs, such as PAT-B, or in our case BLUH. The computation of the AT can be done outside of DCCS on an other computer. Basically all AT programs can be used. There may however be some format adjustment necessary to extract the relevant data from the memory of the host-computer of the DSW-100.

5. REACHED ACCURACY

Comparison analytical and digital Aerotriangulation

project	MDK 2
camera	15 / 23
picture scale	1 : 4500
strips	7
models	43
ground-control	27

	analytical	digital
my (m)	0,06	0,03
mx	0,05	0,04
mz	0,07	0,06

Table 1: Comparison analytical and digital aerotriangulation.

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So far we have triangulated some 2000 models. The triangulated data have been used for consecutive work, like stereoplotting or photo-mechanical rectification of aerial photographs for photo-plans. We could not detect any errors or discrepancies in these consecutive normal stereoplottings, nor have we had any reclamations of the institutions which did the rectifications or other following work.
For some 40 models, we have comparative values of a previous conventional AT, using an analytical plotter and premarked (pugged) points. In both cases the computations were done using the program BLUH. The results of the DAT were more accurate by the factor of 0.7. (see table 1)
We do not give too much weight to this singular value and do not consider this result as representative for the possible accuracy to be obtained with DAT. However in DAT one avoids marking the tie points by any point-transfer-device, which has to be done with utmost accuracy. One even may state, that the accuracy which can be obtained depends totally of the accuracy of the pugging of the tie points. With analytical AT one actually does not measure to picture-points but to some blanc spaces which were more or less precisely scratched out of the emulsion of the film.

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Results of aerotriangulation, Residuals of the groundcontrol							
Nummer	**Y(Easting)**	**X(Northing)**	**Elevation**	**dy**	**dx**	**dz**	
1450012	4439074,80	5742966,67	126,14	-0,02	0,00	0,00	
1450023	4438521,45	5741776,74	135,78	0,07	0,04	-0,02	
1450041	4438401,73	5739848,91	183,63	0,03	-0,04	0,02	
1450053	4438428,33	5738912,25	145,23	0,04	0,03	-0,04	
1450062	4438533,72	5736100,46	153,05	0,02	0,02	0,01	
1450071	4439700,85	5736051,07	161,01	0,01	0,02	-0,03	
1450083	4441767,95	5735949,76	170,86	-0,05	-0,02	0,02	
1450092	4440140,88	5737961,27	142,87	0,05	-0,03	0,01	
1450102	4442542,10	5738043,16	140,47	0,03	0,00	0,01	
1450111	4442961,01	5739665,47	126,09	-0,01	0,03	-0,01	
1450121	4441258,91	5741531,20	148,01	-0,03	0,01	-0,17	
1450132	4441517,77	5742975,62	129,68	-0,04	0,03	0,01	
1450143	4442957,99	5742996,04	134,16	-0,03	0,01	-0,03	
1450152	4442711,06	5741667,94	116,83	-0,04	0,04	0,12	
1450293	4443363,65	5736063,70	166,00	-0,11	0,05	-0,10	
1450351	4438485,58	5734256,47	230,44	0,05	0,04	0,05	
1450361	4438647,57	5732747,39	252,45	0,07	-0,04	-0,06	
1450382	4440200,33	5731605,61	362,04	-0,05	0,00	-0,19	
1450392	4442965,62	5733778,57	216,49	-0,04	-0,04	0,03	
1450401	4442459,27	5731734,18	352,90	0,03	0,00	-0,13	
	Statistics						
	camera			30/23			
	picture scale			1:3700			
	number of photos			401			
	number of models			382			
	number of groundcontrol points			20			
	easting			from 4438687 to 4443392			
	northing			from 5731513 to 5743461			
	mean square differences						
	my = ±0.047	mx = ± 0.028	mz = ±0.072				
	maximal differences						
	My = -0.113	Mx = +0.047	Mz = -0.193				

Table 2: Example of a digital aerotriangulation.

There were some other projects which can be compared to a certain extent. In 1993 and 1994 several blocks were flown with the same technical specifications. The ground control was of a very similar density and the blocks which were triangulated had about the same size. The aerial photography was done with a 30/23 camera, forelap 80%, side-lap 45%, at a scale of 1:3700. The AT in 1993 was done with pugged points and measured on an analytical plotter. The AT in 1994 was done on the DSW 100. Both times for triangulation 60% fore-lap was used. Summarizing these results shows, that an increase of accuracy of about 39%, or an improvement of the average of the residuals from 0.059 to 0.036 m was reached. The details may be taken from tables 2 and 3.

6. LIMITATIONS OF DIGITAL AEROTRIANGULATION

Data of a DAT can only be used with analytical and digital plotters, as with analog plotters picture-coordinates cannot be utilized directly. However there is still the posibility to calculate orintation-data for the analog plotters and use these as orientation aids.

Care has to be taken when selecting the tie- and other points. The area to be scanned may not have any disturbingly differing detail which could cause the automatic correlation to fail.

	analytical (1993)			digital (1994)		
Project	JER	NGL 1	NGL 2	QDG 1	QDG 2	QDG 3
camera	30 / 23	30 / 23	30 / 23	30 / 23	30 / 23	30 / 23
picture scale	1 : 3700	1 : 3800	1 : 3700	1 : 3700	1 : 3700	1 : 3700
strips	10	16	16	18	12	9
pictures	189	354	338	401	238	102
models	179	312	299	382	226	93
ground-control	10	40	46	20	15	8
my (m)	0,03	0,06	0,05	0,04	0,04	0,03
mx	0,05	0,08	0,06	0,03	0,03	0,02
mz	0,04	0,09	0,07	0,07	0,05	0,01
	0,12	0,23	0,18	0,14	0,12	0,06
		ms 0,059 m			ms 0,036 m	

Table 3: Results of analytical and digital aerotriangulations.

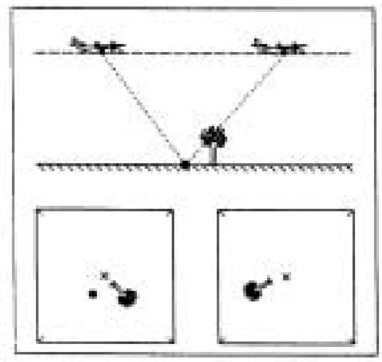

Figure 2

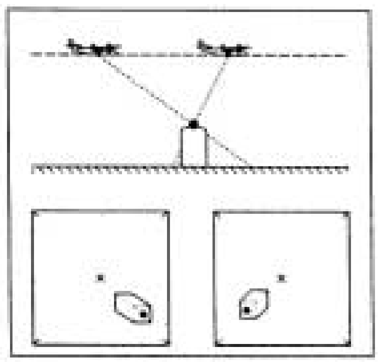

Figure 3

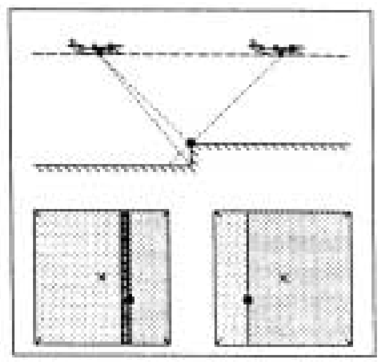

Figure 4

For instance, if some branches, even of a leafless tree are protruding into the patch to be scanned, the automatic correlation may not work. With stereo-viewing on an analog or analytical instrument the operater may overcome that deficiency at least to some extent. One may however use manual correlation also on the SDW 100, but this pin-point accuracy is far inferior to the automated correlation (see Fig. 2).
Still more disturbing is the fact, that automatic correlation quite often fails, when signalized ground-control, such as pillars, are protruding from the ground. Again the operator may save some of these points using manual correlation, but again with loss of accuracy. (see Fig. 3)
One more quite common cause of correlation failures are objects such as curb-stones, walls or steep terraces, which may not be visible in the following photograph, due to the perspective foreshortening. (see Fig. 4)
Knowing that, one can try to avoid such unfavourable shaped points right from the beginning of the project planning. Stereo-viewing devices have so far not shown satisfactory results, but one could well think of possible gadgets, which would overcome these drawbacks, at least to some extent.

7. CONCLUSION

Digital Aerotriangulation is certainly a very powerful tool and fully applicable for a very wide range of projects. There is a pronounced gain in accuracy and also a substantial time-saving factor when DAT is applied. This is not at all devalued by the fact that there are limitations of some sort, which can be avoided to a great extent by careful planning the selection of the tie points. Naturally there are projects which still can be carried out using less sophisticated instrumentary. For these projects the older instumentation has still its value. But **digital photogrammetry** has started and it will certainly claim its proper place in the field of photogrammetry in the very near future.