PHODIS AT - An Automated System for Aerotriangulation

Josef Braun, Liang Tang and Rasmus Debitsch
Carl Zeiss, D-73446 Oberkochen, Germany

Commission II, WG II/5

KEY WORDS: Surveying, Automation, Triangulation, Aerial, Digital, Automatic Aerotriangulation

ABSTRACT

Aerotriangulation is an essential task in photogrammetry. The most laboured and time-consuming work in an analytical aerotriangulation is still the block preparation and measurement of tie and control points. To meet the needs from the photogrammetric practice, an automated system for aerotriangulation was developed. The system is called **PHODIS AT** and is a new member of the digital photogrammetric image processing system PHODIS from Carl Zeiss. The system is composed of the block preparation, the fully automatic tie point determination, the semiautomatic control point measurement and the interface to diverse block adjustment programs. The key feature of the system is the fully automatic determination of tie points in images of a block. Components of PHODIS AT are described in this paper. First results achieved by processing various blocks from the photogrammetric practice are presented and evaluated. It could be shown that the aerotriangulation conducted by PHODIS AT can reach the same level of accuracy as that of the analytical one and is even much more economic for the practice.

KURZFASSUNG

Die Aerotriangulation ist eine essentielle Aufgabe der Photogrammetrie. Die Blockvorbereitung und Punktmessung ist bis heute die mühevollste und zeitaufwendigste Arbeit in der analytisch durchgeführten Aerotriangulation. Um den Anforderungen der photogrammetrischen Praxis gerecht zu werden, wurde ein automatisches System für die Aerotriangulation entwickelt. Das System heißt **PHODIS AT** und ist Teil des digitalen photogrammetrischen Bildverarbeitungssystems PHODIS von Carl Zeiss. Das System unterstützt die Blockvorbereitung, die vollautomatische Verknüpfungspunktmessung, die semiautomatische Paßpunktmessung und verfügt über eine Schnittstelle zum Anschluß unterschiedlicher Blockausgleichungsprogramme. Der Kern des Systems ist jedoch die vollautomatische Messung von Verknüpfungspunkten in Bildern eines Blockes. Im vorliegenden Beitrag werden die Komponenten von PHODIS AT beschrieben. Die ersten Ergebnisse, die durch die Bearbeitung verschiedener Blöcke aus der photogrammetrischen Praxis erzielt wurden, werden vorgestellt und beurteilt. Es zeigt sich, daß die Aerotriangulation mit PHODIS AT dasselbe Genauigkeitsniveau erreichen kann wie die analytische Aerotriangulation, aber viel wirtschaftlicher für die Praxis wird.

1 Introduction

Aerotriangulation is an essential task in photogrammetry. Digital photogrammetry is characterized by the high automation of individual processing procedures and brings much more economy to the photogrammetric practice. Digital terrain models, for instance, can be generated automatically from digital or digitized aerial images and so can digital orthoimages thereafter. Using digital techniques, aerotriangulation can also be automated now in order to meet the needs from the practice. Since early nineties, research and development of algorithms for automating aerotriangulation have been conducted at several institutions (eg. Tsingas, 1992; Schenk/Toth, 1993; Tang/Heipke, 1993; Ackermann/Tsingas, 1994; Toth/Krupnik, 1994) and now a stage has been reached for practical realization (eg. Ackermann, 1995; Krzystek et al., 1995; Mayr, 1995; Schenk, 1995; Tsingas, 1995).

PHODIS AT is a system that affords fully automatic tie point determination and semiautomatic measurement of control points for aerotriangulation. The high degree of automation offered by PHODIS AT simplifies and accelerates block preparation and post-processing considerably. Errors that occur in classical aerotriangulation due to misinterpretations or wrong entries are virtually excluded with PHODIS AT by means of its automated procedures and program checks.

PHODIS AT is a new member of the digital photogrammetric image processing system PHODIS from Carl Zeiss. A complete digital photogrammetric production chain can be established by PHODIS members (cf. Table 1). Using the chain, the whole photogrammetric production can be conducted in a very economic way as mentioned before and, on the other hand, digital products make a direct integration of photogrammetry with geographic information systems possible. In this sense, PHODIS AT plays a very essential role for further automatic procedures.

Table 1: PHODIS Product family

PHODIS Product	Photogrammetric Application
PHODIS SC	photogrammetric scanning system
PHODIS AT	automated digital aerotriangulation
PHODIS ST	digital stereoplotting
PHODIS TS	automatic DEM generation
PHODIS OP	digital orthoprojection
PHODIS M	monoplotting
PHODIS Base	basic PHODIS tools

During the conception of PHODIS AT, special attention was payed to the following aspects:

- Ease of operation,
- Handling of any block configurations,
- Handling of large blocks which cannot be measured in one run due to the huge amount of data,
- Robust tools for the fully automatic determination of tie points and the semiautomatic measurement of control and new points,
- Data compatibility with various block adjustment programs,
- Integration in the work flow of PHODIS and analytical plotting systems controlled by programs such as PHOCUS and P-CAP.

Since the terms "fully automatic", "semiautomatic" and "automatic" are used in different ways in the context of aerotriangulation, we should like to define them at this point:
Fully automatic measurement is the image point measurement without any human interaction.
Semiautomatic measurement is the automation-aided image point measurement with human interaction.
Automatic or automated measurement is the summary of fully or semiautomatic image point measurement.

Further definitions:
New point is a point, which lies in a very distinct position in the images and is chosen and measured by a human operator. Its three-dimensional object coordinates will be kept after the block adjustment for further uses.
Tie point is an image point, which ties the neighbouring images together. In PHODIS AT, tie points are usually determined by the fully automatic measurement procedure.

Aerotriangulation by PHODIS AT can be broken down in 4 steps:

- Block preparation,
- Block measurement,
- Block adjustment and
- Block post-processing.

These steps are described in more detail in the following.

2 Block preparation

Block preparation takes a lot of time with the currently used and feasible aerotriangulation methods. Points have to be preidentified with the help of image prints. Point numbers have to be assigned, and the points have to be marked for transfer, often by means of a point transfer instrument.

These procedures are omitted completely by PHODIS AT. The following data and information are required for the block preparation in PHODIS AT only:

- scanned images with a resolution ranging from 7 µm to ca. 60 µm,
- per image: the image number, the flight number if necessary, the approximate projection center and the flight direction,
- camera protocol, and
- ground control information.

The approximate projection centers can be derived either from the log file of a flight planning system such as T-FLIGHT, or simply by taking the data from the image center plan. Of course, they can also be taken from program systems, which derive the projection centers from GPS flights. GPS data provide precise information on projection centers but are absolutely not a prerequisite for aerotriangulation measurement by PHODIS AT.

With the help of the above information, PHODIS AT creates a graphical block display, computes the approximate overlaps and determines the normal and crossing strips of the block. The link between the flight and image numbers and the image files is also established. In this context it is irrelevant if the computer has direct access to the image files or not.

Because of the large amount of data per image (cf. Table 2) it may be assumed that the computer does not have direct access to all images of a block. This is why PHODIS AT allows subdividing the whole block in subblocks of any size, which can be processed individually and adjusted together later on. During the definition of subblocks, care should be taken to ensure that they overlap each other by at least one image strip so that the subblocks can be tied.

Table 2: Memory space required for black/white images

Image resolution	**Data volume for 100 images incl. pyramids**
7 µ	144 GB
14 µ	36 GB
28 µ	9 GB
56 µ	2.3 GB

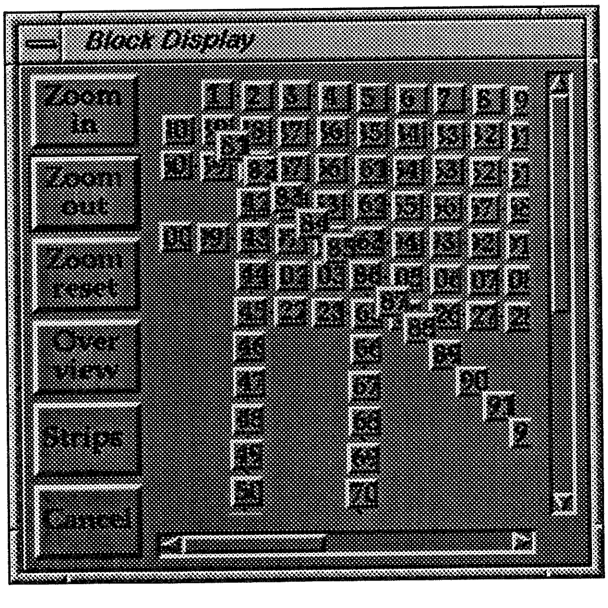
If the image data are stored in compressed form, the data volume can decrease considerably depending on the selected compression factor. However, the file access will be slowed down because the data have to be decompressed during each access operation or the data of the whole subblock have to be decompressed before measurement.

For each subblock, the following operations for the block measurement can be performed automatically:

- Loading of the images of the subblock after removing a previously loaded subblock. For this reason, each image is assigned its own loading and removing procedure.
- Generation of image pyramids, if not available.
- Fully automatic or manual interior orientation if not yet done.

All preparatory work is supported by graphical user windows. They are very easy to use and monitor. Here, the block display (Figure 1) is of particular interest and supports the following functions:

- Schematic display of the block, where the whole block structure is represented by square-formed image symbols,
- Subblock selection, where an arbitrary subblock can be formed by clicking the image symbols to be included,
- Display of the block overview and zooming in and out part of the block,
- Optional display of image icons, image numbers and interior orientation results, and
- Selective turn-on or -off of individual strips.



In order to efficiently conduct the data management in PHODIS AT, a special relational data base (RDB) is used. This adapted RDB allows to add any additional information, that may be required later on, to the existing data.

3 Block measurement

Block measurement is subdivided in three parts: Fully automatic tie point determination, their checking and semiautomatic control and new point measurement. For the measurement itself no additional information is required. Neither overlaps nor any tolerances have to be entered.

The names of the tie points are assigned automatically. The operator only defines a start value and an interval for the new points and the tie points. A name may be numerical and/or alphanumerical. Automatic name assignment ensures that a point name is not assigned repeatedly to different points.

3.1 Fully Automatic Tie Point Determination

Tie points are conjugate points, serving to connect neigbouring images together. The determination of tie points in images does not need to recognize any specific features. Therefore, a full automation of this procedure is possible. A corse-to-fine image matching approach combining the feature-based and area-based techniques supports the fully automatic tie point determination in PHODIS AT. The approach is an extention of the one, which is successfully used for automatic relative orientation in PHODIS ST (Tang/Heipke, 1996; Tang et al., 1996).

The fully automatic tie point determination in PHODIS AT is done in two steps. The first step is called "block formation", serving to connect images of the whole block together on higher pyramid levels with lower image resolution. The second step is called "point tracking", aiming at achieving as high a measuring accuracy of each tie point in images as possible through the rest of pyramid levels.

Feature-based matching (FBM) is used to determine conjugate points in image pairs in the block formation. Using an interest operator, point features are first extracted from images independently and then matched according to certain geometric and radiometric criteria. For a model formed by an image pair in a strip, the matched point pairs are used as observations in a robust bundle adjustment, in which relative orientation parameters and object coordinates of the points are determined and outliers are also eliminated. The orientation parameters and the point object coordinates are then forwarded to the next lower pyramid level in order to repeat the matching procedure. For a model formed by two images from two neighbouring strips, due to the possibly very limited overlap, a robust affine transformation is performed to eliminate outliers in the matching. A manifold tie point can be obtained by finding out the same feature in the common image of the neighbouring models. The final result of this step is a list of tie points in the whole block determined at a so-called intermediate pyramid level. The intermediate level is a pyramid level in which the tie point determination can still be carried out fast enough and from which enough tie points can be generated for a reliable point tracking.

A tie point in the list generated in the step of block formation consists of a point name, number of tie images and a list of these tie images including the point measurements at the intermediate level. In order to precisely measure the image coordinates of the point in the tie images, a least squares matching (LSM) (eg. Ackermann, 1983) is performed pair by pair through the rest of pyramid levels down to the original image resolution at the step of point tracking. Around a given point pair at the intermediate level, a reference and a search window are defined. Six affine parameters and two radiometric ones are calculated between the two windows in an iterative way. For a convergent result of calculation, the cross correlation coefficient between the two windows is then computed. If the coefficient is larger than a threshold, the match is declared as successful. The interest operator is used again in the reference window to find a proper point for transfering to the next lower pyramid level. This point is then transformed to the search window via the affine parameters, defining the corresponding point there. These two points are mapped onto the next lower pyramid level and the LSM repeats. At the end of point tracking, the tie point list is updated with image coordinate measurements in the original image resolution. Since the number of tie points in an image can be unnecessarily large for the block adjustment, the 2-fold tie points are tracked only selectively.

Detailed description of the matching approach can be found in (Tang, 1996).

3.2 Checking the fully automatic measurement

If, during fully automatic measurement, areas such as large water bodies are found in which no or too few tie points could be measured, these are recorded. After the completion of fully automatic measurement, the operator is guided to these areas and can, if required and possible, measure further points either manually or semiautomatically.

For spot checking the fully automatic measurements, the block display affords any image of the block to be displayed in a separate measurement window. There are no limits to the number of measurement windows. Since it is easy to get lost with only one display unit, PHODIS AT allows the measurement windows to be distributed over several display units.

The measurement windows are autonomous entities. They have their own zoom, measuring and display functions. This allows the independent use of each measurement window. In addition, common functions such as a common zoom for all windows are also available.

3.3 Semiautomatic control and new point measurement

Since an automatic identification of ground control points (GCPs) in images is still hardly possible (Gülch, 1995), a semiautomatic GCP measurement is supported in PHODIS AT. The human operator identifies and prepositions a GCP in images. An intensity-based least squares matching algorithm (ISM) (IfP, 1996) takes then the responsibility for an accurate measurement. If new points are required, they also have to be measured semiautomatically. These measurements can be made at any time, i.e. also during fully automatic tie point determination.

The point measurement proceeds as follows:

- Select the manual, semiautomatic or automatic mode of measurement,
- Select the zoom factor desired in the measurement windows,
- Select the name of the GCP to be measured in the GCP list, or activate the new point measurement for the initial

measurement, or click the new point in the point list if it was measured in a measurement window before,

- Preposition the point in the window, where an automatic prepositioning may also be possible (cf. coming up texts),
- In the case of manual measurement, digitize the point in all windows in which it occurs,
- In the case of semiautomatic measurement, digitize the point precisely in one window and approximately in the other ones, where the real measurement is then performed by ISM which is able to reach an accuracy of up to 0.1 pixel size,
- In the case of automatic measurement, digitize the point precisely in one window only, after that the point is transformed to other corresponding windows by means of the exterior orientation parameters and automatically measured by a Multi-ISM, which simultaneously matches the points in all measurement windows. This mode is especially to recommend after the fully automatic tie point determination or after a first block adjustment.

Since GCP measurement can be very time-consuming, in particular if there are many GCPs to be measured, PHODIS AT offers a further option:

- Measure only as many GCPs as required for a first block adjustment,
- Perform the block adjustment,
- Read the exterior orientation parameters of images into PHODIS AT,
- Then the operator is guided to those GCPs that have not yet been measured so that he can measure them as described above.

This method can be used for the whole block or the subblocks, and offers the following advantages:

- The operator is assisted in the search for GCPs.
- Misinterpretation of GCPs is virtually excluded, and the operator does not have to enter point names. This is a common source of errors in conventional aerotriangulation measurement, and their recovery is often very time-consuming.

4 Block adjustment

PHODIS AT intentionally does not include an own block adjustment program. The advantage is that customer-owned block adjustment programs can be linked to PHODIS AT and that the operator does not need to give up his/her familiar system.

Interfaces can easily be created to read and write data between these systems and PHODIS AT. If the adjustment program runs on the same platform as that of PHODIS AT, it can be started directly from the environment of PHODIS AT. Otherwise, the block adjustment program can be started on any other computers.
Adjustment can be done either for the whole block or the subblocks.

5 Block post-processing

5.1 Creation of control and new point sketches

PHODIS AT contains a module for the creation of control and new point sketches in the Postscript format. The appearance of these sketches can be varied by the user. They essentially contain the following elements:

- Overview section from the image file showing the location of the point in the image (coarse image location).
- Detail section of the image showing the precise location of the point in the image.
- Explanatory information such as the name, coordinate values, image file, PHODIS project etc.

5.2 Data editing for further use

The purpose of aerotriangulation is the acquisition of the exterior orientation parameters of the images or the relative and absolute orientation parameters of individual stereo models. PHODIS AT therefore offers the option to read in the data directly into PHODIS and then to use it without further processing in other PHODIS projects, and to create PHOREX or PEX files which can then be read directly into analytical systems from Carl Zeiss.
During this process, stereo models are formed and the exterior orientation parameters of the images are split up in relative and absolute orientation parameters of the models.

Because of the very strong bridging of the images, parallaxes are minimized optimally in the models. Thus, a new relative or absolute orientation in an analytical plotter is neither required nor recommended. What an operator can do for orientation is only the model checking. Since it is not necessary to measure GCPs or new points in every model during the block measurement, tie points determined by the fully automatic measurement can be used for model checking. The quality of a model in an analytical plotter can be checked as follows:

- A planimetric check can be achieved by setting existing GCPs or new points. If there are none of GCPs or new points available, those tie points that are suited for a planimetirc check can be used.
- Elevation checking can be performed by using any GCP, new or tie point.

6 Practical results

Four blocks were used to test the reliability and accuracy of aerotriangulation by PHODIS AT. These blocks meet the following requirements: different image resolutions, different image scales, different camera focal lengths and different image materials.

Block Forssa:
This block is the OEEPE block provided for the OEEPE test "Digital Methods in Aerial Triangulation". The block consists of 28 images with 60-70% forward and 15-40% side overlap. The images show a flat, urban and industrial area.

Block Moeck:
The block consists of 15 images with ca. 60% forward and 20-30% side overlap. The images present a rural, woody and hilly landscape.

Block Graz:
This block is an inner city flight with a long focal-length camera. Color images with ca. 60% forward and 30% side operlap show a varied city area.

Block Echallens:
This block is featured by high forward (ca. 80%) and side overlaps (ca. 60%), and presents a rural landscape.

The results of the measurements and adjustments achieved are shown in Table 3. None of the 4 blocks required interactive intervention for tie point measurement. The robust block adjustments carried out by PAT-B eliminated approximately 4% of the tie points determined automatically, regardless whether the images show wooded, rural or city areas.

PHODIS AT currently needs approximately 6 minutes for measuring an image on a Silicon Graphics Workstation with R4400 processor and 200 MHz.

Table 3

	Forssa	**Moeck**	**Graz**	**Echallens**
No. of Images	28	15	12	9
Resolution	15	15	28	20
σ_o (µm)	6.4	6.9	8.4	4.1
σ_o (µm) (analytisch)	3.5		7.2(P) 23.0(E)	
Image scale	4000	7000	4000	5500
Focal length	153	153	305	153
No. of GCPs	55	7	36	10
No. of tie points				
6-fold	31	19	4	11
5-fold	49	48	26	20
4-fold	228	133	102	68
3-fold	1238	1003	819	434
2-fold	3732	1862	2701	1509
Image rms x/y (µm)	2.42 3.74	2.51 3.92	3.35 5.62	1.89 2.68
Object rms x/y/z (m)	0.015 0.016 0.022	0.016 0.012 0.018	0.028 0.025 0.047	0.013 0.012 0.015

P = planimetry; E = elevation (computed by PAT-M)

When considering the adjustment results, one can focus on σ_o. σ_o indicates the accuracy of the automatically measured points and can be used for comparision with that of an analytical aerotriangulation. The analytically determined values given in Table 3 were obtained at those points marked by a point transfer instrument. The accuracy of digital aerotriangulation amounts to ca. 0.2 to 0.3 pixel size. The digitally determined exterior orientations are clearly more reliable than that of the analytically determined ones because they are obtained with a much heigher redundancy. It shows in Table 3 that the larger the overlap is (eg. block Echallens), the better the block adjustment results, which has already been known for a long time from the block adjustment theory.

Our tests have shown that the accuracy of block adjustment does not decrease linearly with the resolution of the images. Halfing the image resolution (e.g. 30µm instead of 15µm) results in an accuracy loss of ca. ¼. This can be explained by the large number of points, which ensures that the result is very stable despite the reduced resolution. This is true for good image material. If the quality of the image material is poor, the loss of accuracy can be larger, which can be shown by the block Forssa. An adjustment accuracy of $\sigma_o = 11.9$ was obtained for this block with an image resolution of 30 µm.

For the block Graz we have detailed information on the time and costs for an analytical aerotriangulation (Ganster/Xu, 1994). If one considers only the time for analytical measurement (Table 4) and compares it with the derived time for the digital aerotriangulation conducted by PHODIS AT (Table 5), it becomes clear how economic the digital aerotriangulation can be.

Since the time for the digital aerotriangulation is derived, 20% error margin is added. Despite this addition, great time difference can be found. Considering that much of the given time is pure computing time (eg. image scanning with autowinder, pyramid generation, automatic interior orientation, automatic tie point determination) by the digital aerotriangulation measurement, it becomes even more obvious how economic the digital aerotriangulation by PHODIS AT is.

Block preparation and measurement for 659 images:

Table 4

Analytically	**Hours**
Organisation	30
Area specification	105
Point transfer	600
Data management	25
Measurement (*)	1200 (220)
Total	1960 (980)

* The 1200 hours result from special demands. In normal cases, one can expect to measure up to 3 images per hour which results in 220 hours.

Table 5

Digitally	**Hours**
Scanning	165 (15 min/image)
Data management	220 (20 min/image)
Block definition	8
Pyramids computation	33 (3min/image)
Automatic interior orientation	11 (1 min/image)
Automatic measurement	66 (6 min/image)
GCP measurement & adjustment (**)	60 (4 min/point)
Total	555 + 20% = 666

(**) In the block there are 909 GCPs. Four minutes per GCP are assumed. This is very liberal especially when considering that PHODIS AT can guide operator to the GCPs after a first block adjustment. System-guided GCP measurement does not require more than 2 minutes per point.

7 Conclusion and Outlook

PHODIS AT is a new system available on the market that performs fully automatic tie point determination and semiautomatic control point measurement for aerotriangulation. PHODIS AT is already proving itself in practical use. The high degree of automation makes aerotriangulation more economic. The vision is near at hand that a chain can be build up which allows automatic image scanning, automatic aerotriangulation, automatic DEM and orthoimage generation, and even automatic stereoscopic or monoscopic data aquisition for geographic information systems. These prospects are very promising and can be achieved already in the near future.

References:

Ackermann, F., 1983. High Precision Digital Image Correlation. Schriftenreihe des Instituts für Photogrammetrie der Universität Stuttgart, Heft 9, 231-243.

Ackermann, F., 1995. Automatic Aerotriangulation. In Proceedings 2nd Course in Digital Photogrammetry, Bonn.

Ackermann, F., Tsingas, V., 1994. Automatic Digital Aerial Triangulation. ASPRS/ACSM Annual Convention, pp. 1-12, Reno

Ganster, W., Xu, X.M., 1994. Aerotriangulation Graz. Endbericht des Magistrat Graz 10/6.

Gülch, E., 1995. Automatic Control Point Measurement. 45th Photogrammetric Week, Stuttgart, pp. 185-196

IfP, 1996. Automatische Punktübertragung. Institute for Photogrammetry (IfP), Stuttgart University.

Krzystek, P., Heuchel, T., Hirt, U., Petran, F., 1995. A New Concept for Automatic Digital Aerial Triangulation. 45th Photogrammetric Week, Stuttgart, pp. 215-223.

Mayr, W., 1995. Aspects of Automatic Aerotriangulation. 45th Photogrammetric Week, Stuttgart, pp. 225-234.

Schenk, T., 1995. Zur automatischen Aerotriangulation. Zeitschrift für Photogrammetrie und Fernerkundung (ZPF), 3/1995, 137-144.

Schenk, T., Toth, C., 1993. Towards an Automated Aerial Triangulation System. ASPRS/ACSM Annual Convention, pp. 652-660, Reno.

Tang, L., 1996. Toward Automatic Aerotriangulation. Paper accepted for Geoinformatics'96 Wuhan, Wuhan, P.R. of China, October 16-19, 1996.

Tang, L., Heipke, C. (1993): An Approach for Automatic Relative Orientation. Optical 3-D Measurement Techniques II., Grün/Kahmen (Eds.), Wichmann, Karlsruhe, 347-354.

Tang, L., Heipke, C., 1996. Automatic Relative Orientation of Aerial Images. Photogrammetric Engineering & Remote Sensing, Vol. 62, No. 1, 47-55.

Tang, L., Poth, Z., Ohlhof, T., Heipke, C., Batscheider, J., 1996. Automatic Relative Orientation - Realization and Operational Tests. Paper accepted for ISPRS Congress'96, Vienna, Austria, July 9-19, 1996.

Toth, C., Krupnik, A., 1994. Concept, Implementation and Results of an Automated Aerial Triangulation System. ASPRS/ACSM Annual Convention, pp. 644-651, Reno.

Tsingas, V., 1995. Operationl Use and Empirical Results of Automatic Aerial Trinagulation, 45th Photogrammetric Week, Stuttgart, pp. 207-214.

Tsingas, V., 1992. Automatisierung der Punktübertragung in der Aerotriangulation durch mehrfache digitale Zuordnung. DGK Reihe C Heft 392, München.