

---

## AERIAL TRIANGULATION DATA ACQUISITION USING A LOW COST DIGITAL PHOTOGRAMMETRIC SYSTEM

Andrea LINGUA\*, Fulvio RINAUDO\*

\*Politecnico di Torino, Italy  
Department of Georesources and Land  
[lingua@polito.it](mailto:lingua@polito.it), [rinaudo@polito.it](mailto:rinaudo@polito.it)

Working Group II/3

**KEY WORDS:** Aerial triangulation, Automation, Data acquisition

### ABSTRACT

Low Cost Digital Photogrammetric Systems (LC-DPS) are based on modular hardware and software, which fulfil standard map production requirements at a reasonable cost and offer most of the advantages of the digital technique.

Algorithms and procedures for scanning aerial images by means of DTP scanners, the matching of selected points and automatic procedures for measuring DEM heights are now currently used.

These instruments should be completed with a procedure for aerial triangulation data acquisition using the automation allowed by the recent development of digital techniques and modern PC performances.

A software has been implemented and tested in order to perform the following procedures: automatic interior orientation, search of interest points and automatic selection of homologous points, robust validation and outlier detection by means the LMS estimator, automatic selection of image and strip tie-points.

The algorithms and procedures are described in detail and the achieved results are shown in terms of quality and reliability.

### 1. INTRODUCTION

In the last four years a lot of digital photogrammetric systems, based on PC hardware, have been offered to surveyors at very low prices. This is mainly due to the accepted use of geometrically calibrated DTP scanners in the hard copy scanning process of photographic images, to the implementation, into PC platforms, of powerful software and to the continuous increase of PC performances. The precision reached by these systems satisfies the normal requirements stated by the most frequently used guidelines for cartographic production.

An acquisition unit and a restitution unit constitute a standard Low-Cost Digital Photogrammetric System (LC-DPS). The acquisition unit has to produce a digital image where the user can directly read the central perspective co-ordinates of each pixel. For aerial applications, the hardware of the acquisition unit is a DTP scanner equipped with a transparency adapter. The software performs the calibration of the acquired images, in order to recover the geometric deformations of the scanning process, and the computation of the interior orientation parameters, to transform the co-ordinates of the pixel, which refer to the reference system of the digital image, into the "fiducial" reference system. The image is not resampled, but all these parameters are linked to the image: the calibration and the interior orientation are then made on-line during the successive step by the restitution unit.

The restitution unit has to perform the computation of the exterior orientation parameters (usually by aerial triangulation), the restitution of a stereo-model and the production of DTM's and orthophotos. All the required software run on a standard PC platform.

At present, the automation of the commercial software is not yet comparable to the one implemented in high precision digital photogrammetric systems. Only calibration of the scanned images in the acquisition unit and DTM and orthophoto production are fully automatic procedures.

In this paper, the authors show the results obtained using a software implemented on a standard PC to automatically solve the interior orientation and the acquisition of the primary data for the aerial triangulation adjustment of a block. The software has been tested on a block of 3 strips (25 aerial images) at 1:15000 scale (useful for a 1:5000 map) acquired at 700 dpi resolution (pixel size 36  $\mu\text{m}$ ) with a UMAX MIRAGE II scanner. The PC that was used is based on an INTEL PIII/500 MHz processor.

## 2. AUTOMATIC INTERIOR ORIENTATION OF AN AERIAL IMAGE

The implemented software performs automatic collimation of the fiducial marks of an aerial image. A least squares matching process, using a theoretical image of the fiducial mark as a “target image”, detects the position of the fiducial mark inside the digital image. When all the co-ordinates of the fiducial marks have been detected, the common algorithms for the interior orientation (planar transformation) are used.

It is well known that recent metric aerial cameras have standard fiducial marks that allow an automatic link to the calibrated co-ordinates, but in standard works, a great deal of old aerial cameras are still in use. In this last case there are many different

fiducial mark shapes that must be considered. In order to offer the maximum generality to the procedure, a software for the generation of the target of the used image fiducial marks, has been set up.

All the fiducial marks can be considered as a mixture of circles, segments and rings (see figure 1). Starting from these primitives, all kinds of fiducial marks can be generated and used as targets in the matching procedure (see figure 2).

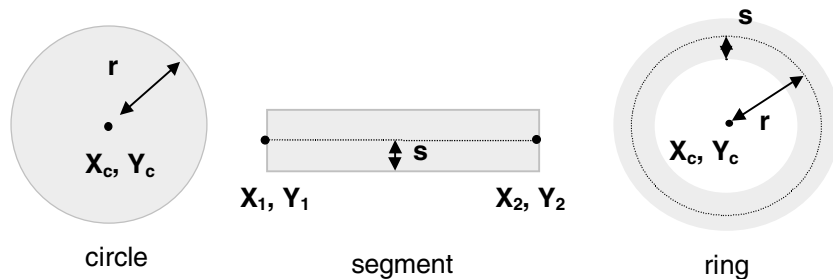


Figure 1. Geometric elements of a fiducial mark

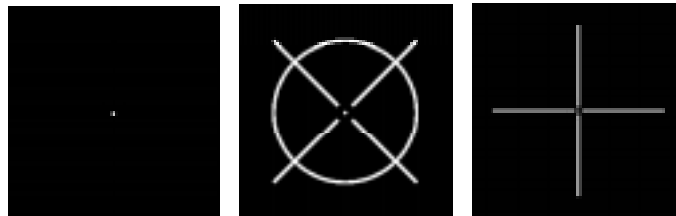


Figure 2 . Target of the Wild and Zeiss aerial cameras generated by the software

The software for the collimation of the fiducial marks starts by finding the centre of the digital image of the photo and considers the four sectors of the image. In the upper-left and lower-right sectors of the image, a pixel and a sub-pixel matching finds the firsts two fiducial marks, considering a large “search matrix”. A planar transformation is computed in order to reduce the “search matrix” of the other marks and to speed up the matching (see figure 3).

Using a PENTIUM II/400 Mhz based PC, the complete interior orientation of an image required 100 s. The correlation coefficient for the marks range from 0.9 to 0.95: figure 4 shows a comparison between a target and a real mark.

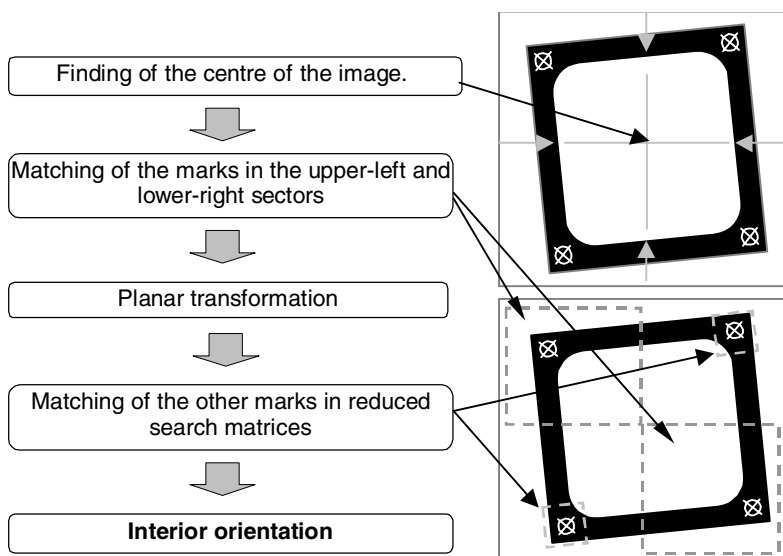


Figure 3. Automatic matching of the fiducial marks

In order to evaluate the precision of the automatic collimation, all the fiducial marks of the 25 images were measured using an analytical plotter (DIGICART 40 by GALILEO with  $\pm 3 \mu\text{m}$  of m.s.e. in co-ordinate measurements). The two sets of co-ordinates were fitted with a least-squares technique; the absolute discrepancies of the co-ordinates of the marks do not exceed  $5 \mu\text{m}$  ( $\cong 0.2$  pixel). Table 5 shows the discrepancies of three images of the block.

The parameters of the interior orientation are recorded with the parameters for the correction of the geometric deformations of the scanner and linked to the image that is now ready for the restitution unit.



Figure 4. Example of target and real mark

Mark	Image n. 2361			Image n. 2391			Image n. 2378		
	$\Delta x$ [ $\mu m$ ]	$\Delta y$ [ $\mu m$ ]	$\Delta s$ [ $\mu m$ ]	$\Delta x$ [ $\mu m$ ]	$\Delta y$ [ $\mu m$ ]	$\Delta s$ [ $\mu m$ ]	$\Delta x$ [ $\mu m$ ]	$\Delta y$ [ $\mu m$ ]	$\Delta s$ [ $\mu m$ ]
1	-4	-3	5,0	3	2	3,6	-2	0	2,0
2	2	2	2,8	-2	-4	4,5	3	1	3,2
3	1	2	2,2	-3	1	3,2	-1	-1	1,4
4	1	-1	1,4	2	1	2,2	0	0	0,0

Table 5. Discrepancies between automatic and manual co-ordinate measurement

### 3. AUTOMATIC DATA ACQUISITION FOR AERIAL TRIANGULATION

The software, named DIGITRIA, first runs strip by strip, according to the following steps: automatic homologous point selection of the models of the strip, automatic selection of the image tie-points, manual collimation of the control points and independent model adjustment of the strip. All the matching of the tie and control points are done in such a way to create two different series of co-ordinates: one for the independent model approach (matching under the relative orientation control) and one for the bundles approach (matching in the two directions of the linear and height parallaxes). The control points are not considered as signalled points but as natural points: for this reason the operator has to find the control points.

When all the strips have been managed, the software selects the tie-points across the strips from all the tie-points acquired in the previous steps, and performs an independent model adjustment of the block, to give a good approximation of the unknowns for an efficient bundle block adjustment. Furthermore, the independent model approach allows one to easily point out gross errors and outliers that cannot be efficiently managed by bundle block adjustments.

A first gross error and outlier detection, from the automatic matching of the tie-points and from the individuation of the control points, can be performed during the data acquisition phase.

In the following paragraphs all the steps of DIGITRIA are described in detail.

#### 3.1 Homologous points selection

A large number of the known automatic homologous point searching procedures are based on pyramid images. Different algorithms were used in the past: feature extraction and matching (by Liang and Heipke) or relational matching (by Wang) are the best-known methods. Considering the power of modern PC platforms, a different approach has been used to speed up computation. The proposed software always uses the maximum resolution image: considering the overlapping part of two adjacent images, the Förstner operator is used to extract the best points for the matching. In this way, two different samples of points are formed. For each selected point on the left image, the correlation coefficient of the selected points on the right image is computed: the homologous point is the right image one, with the maximum value of the correlation coefficient. A sub-pixel matching is performed for each

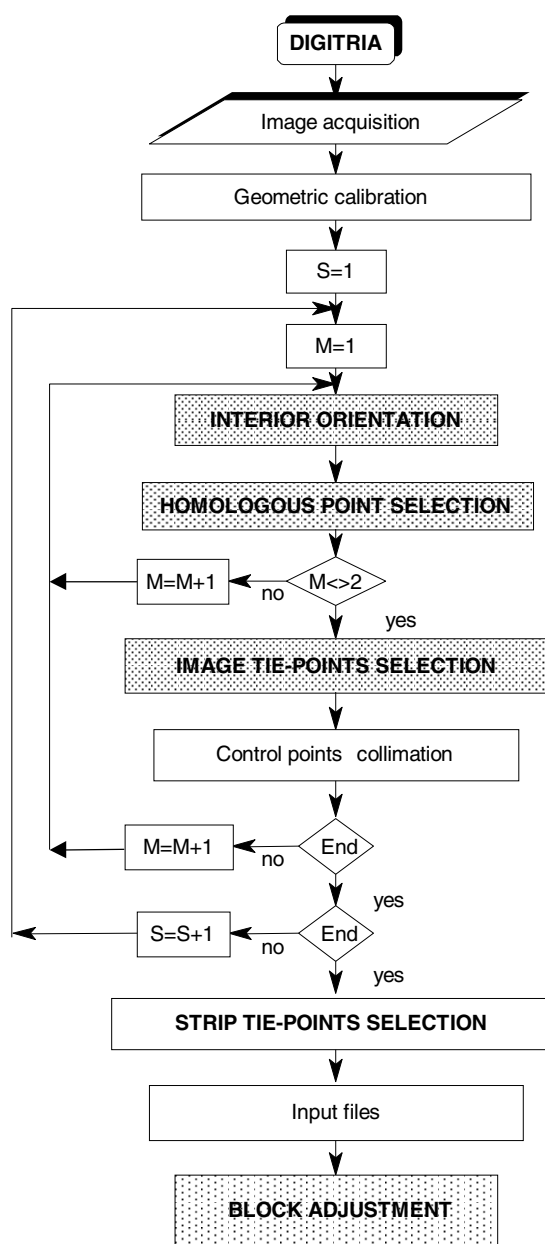


Figure 6. Aerial triangulation data acquisition procedure

couple and, after the resampling, only the couples with a correlation coefficient, that is the higher than the first one are considered as accepted homologous points.

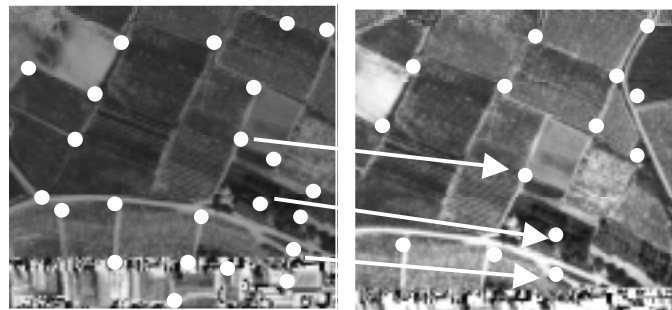


Figure 7. Automatic selection of homologous points

In order to avoid outliers due to incorrect matching, the Least Median Squares robust estimator is applied using a relative orientation procedure.

As is well known, this estimator has a greater than 50% breakdown point (i.e. the estimator can work efficiently on samples where more than 50% of the observations are affected by gross errors) and its estimations are not influenced by leverage points.

Tables 8 and 9 show the number of homologous points found during the first step and the number of accepted points by the LMS estimator in the models of a strip. The mean and maximum residual parallaxes are also shown after the relative orientation in both cases.

Images	Homologous points	Mean parallax [μm]	Max parallax [μm]
2383-2382	47	0.01	7
2382-2381	91	-0.39	8
2381-2380	47	0.00	9
2380-2379	25	-0.01	6
2379-2378	65	0.01	7
2378-2377	46	0.00	2
2377-2376	32	-0.02	4
2376-2375	27	-0.31	3
2375-2374	68	0.29	6

Table 8. Homologous points selected and relative orientation results (without LMS estimator)

Images	Homologous points	Mean parallax [μm]	Max parallax [μm]
2383-2382	20	0.00	3
2382-2381	33	0.00	4
2381-2380	22	0.00	5
2380-2379	24	0.00	4
2379-2378	44	0.00	3
2378-2377	19	0.00	5
2377-2376	26	0.00	4
2376-2375	37	0.00	3
2375-2374	26	0.00	5

Table 9. Homologous points selected and relative orientation results (with LMS estimator)

The achieved results demonstrate that the proposed outlier detection, using the LMS estimator, is necessary to obtain a satisfactory result.

The computing time for a complete search and validation of homologous points in each couple of images is about of a 600 s.

### 3.2 Image tie-point selection

Let us consider two adjacent models. The image tie-points are the ones that are selected both on the first model and on the second model. DIGITRIA selects all the points, in the central image, that have been linked to a point of the first image and to a point of the second image (see figure 10). This selection is made using the image co-ordinates of the homologous points selected in the previous step.

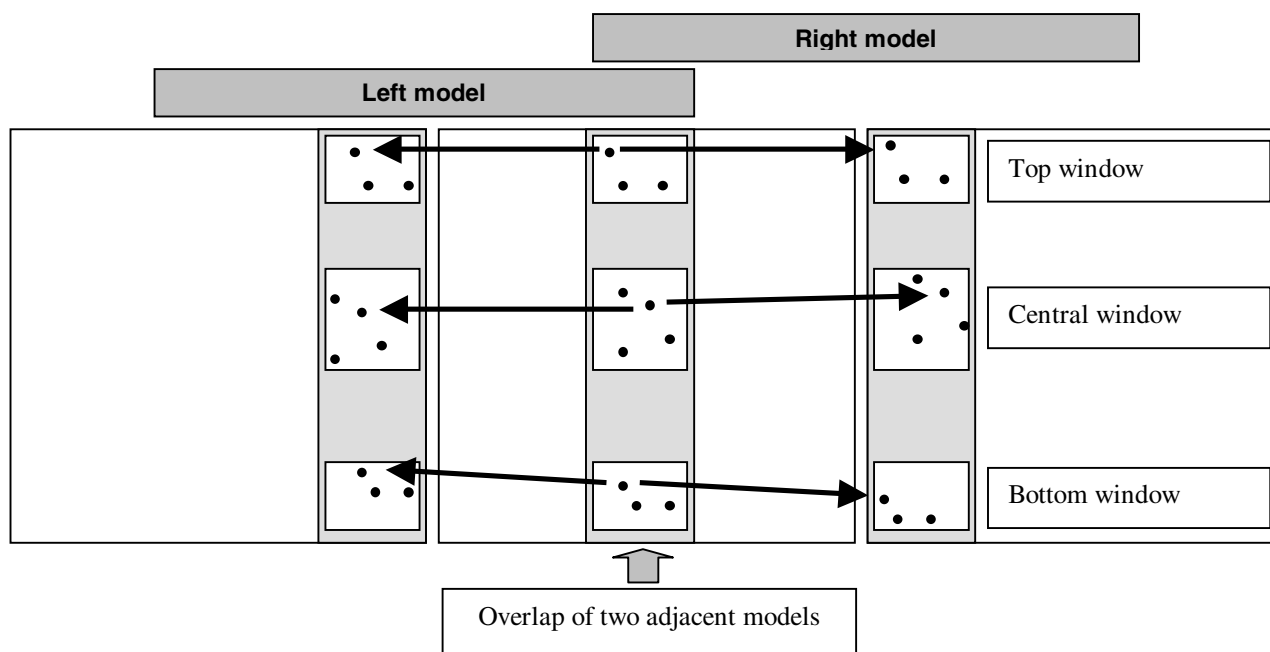


Figure 10 – Automatic search of image tie-points

At least three tie-points have to be selected for each image in the classical positions. If the procedure does not succeed, the software asks the user to choose the required points. Table 11 shows the number of the image tie-points selected in one of the strips of the block used for the test.

At the end of this step, the user has to measure the co-ordinates of the control points (a rough collimation refined by the software by means of a least squares matching) and the program makes an independent model adjustment of the strip. The same procedure is performed for all the strips of the block.

Images	N. tie-points
2383-2382	10
2382-2381	15
2381-2380	9
2380-2379	12
2379-2378	19
2378-2377	25
2377-2376	30
2376-2375	17
2375-2374	10

Table 11. Selected image tie-points

### 3.3 Strip tie-point selection

When all the strips have been oriented, the side-lap of the strips is defined with sufficient approximation. Then DIGITRIA selects all the image tie-points that are present in two adjacent strips comparing the absolute co-ordinates of the tie-points selected in the previous step. The searching procedure starts from the overlapping portion of 4 models (6 images); furthermore also the overlapping portions of only two models are analysed.

If the number of selected tie-points is not sufficient (i.e. at least one tie-point for each image) the user can manually integrate the selection made by the software.

In the test block used at least 4 strip tie-points have been automatically selected for each model: almost two of them are in the overlapping portion of four models. These two last steps required about 600 s of computing time in the test block.

### 3.4 Aerial triangulation adjustment

In order to test the complete procedure of automatic data acquisition, a bundle block adjustment has been carried out using the CALGE software developed at the Politecnico di Milano.

All the images of the test block (see par. 1) have been managed by DIGITRIA and the input files for the adjustment program have been written. Table 12 shows some general results of the adjustment.

The achieved results fit the requirement of a block adjustment in the standard guidelines for 1:5000 map production.

		<b>E</b> [m]	<b>N</b> [m]	<b>H</b> [m]
<b>Control-points</b>	Max	0.86	0.60	0.75
	Mean	0.09	-0.05	-0.08
	Sqm	0.45	0.43	0.35
<b>Tie-points</b>	Sqm	0.10	0.19	0.28

Table 12. Aerial triangulation adjustment

## 4. CONCLUSIONS

The achieved results show that automatic data acquisition for aerial triangulation is now possible using simple and cheap hardware. The lack of images, due to limited geometric resolution, which is essential for easy use of a PC, can be made up for using sophisticated software. In particular, “interest operators” and “robust estimators” are the algorithms that would allow the highest level of automation to the procedure.

The computation times obtained in the test and practical experience have shown that a 50% reduction in the time usually needed in traditional approaches is possible: only computing time is required and the operator, in most cases, only discusses the final results.

Obviously, even though it is possible to imagine an inexperienced user of the software, the discussion and the subsequent acceptance of the results have to be carried out by an expert photogrammetrist.

The implementation of the proposed approach in LC-DPS will help form a complete digital photogrammetric system that is able to fit, at a reasonable cost, the usual cartographic production requirements.

## REFERENCES

- Akermann F., (1995) - *Automation of Digital Aerial Triangulation* - Second course of Digital Photogrammetry, Bonn.
- Dequal S., Lingua A., Rinaudo F. (1996) - *Matching techniques and algorithms for some basic photogrammetry procedures in the Low Cost Digital Photogrammetry System* - International Archives of Photogrammetry and remote Sensing, Vol XXXI, p. B1, comm. I.
- Krzystek P. (1997) - *Automatic Aerial Triangulation: conceptual aspects and new investigation* – Third course of Digital Photogrammetry, Bonn.
- Rousseeuw P.J.; Leroy A.M. (1987) – *Robust regression and outlier detection* - Wiley Series in probability and mathematical statistics.
- Hampel F. R., Ronchetti E. M. , Rousseeuw P. J. (1986) – *Robust statistics: the approach based on influence functions* - Wiley Series in probability and mathematical statistics
- Huber, P.J. (1981) – *Robust Statistics* –Wiley Series in probability and mathematical statistics
- K. Kraus (1997) – *Photogrammetry* (voll.1 and 2) – Ferd. Dümmlers Verlag - Bonn