

## **"STEREOBIT/20" AND "RESEAU": A NEW PHOTOGRAMMETRIC ANALYTICAL SYSTEM FOR SEMIMETRIC IMAGES. THEORY AND SOFTWARE**

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### **ABSTRACT**

The use of semimetric cameras in the architectural applications of photogrammetry is becoming more and more consolidated.

The new "motorized" STEREOBIT/20, a simple but rigorous analytical plotter, based on the "Inghilleri" principle of stereoplotting (only two stepping motors for the parallaxes control) appeared on the market only a few months ago. This instrument is equipped with an 80286 PC-DOS computer. It costs less than 1/4 of the price of the usual analytical plotters. It operates with aerial photos (9"x9") and the smaller terrestrial metric, semimetric or non metric images (slides or paper prints). Accuracy, easy to use, software availability, give to this instruments the best cost/performance ratio.

RESEAU is a user-friendly software specially designed for the semimetric image plotting. It manages all the reseau images available on the market.

Calibration is based on affine or homographic transformations, prepared in a preliminary "calibration" phase and achieved in real time during the restitution phase.

The calibration, orientation and restitution procedures are computer assisted with an efficient user interface based on "pop-up menus".

Theory and software organisation are illustrated in the paper.

### **1. INTRODUCTION**

The increasing availability of a series of "semi-metric" cameras, produced by different manufacturers (ROLLEI, PENTAX, HASSELBLAD, etc.) offers the photogrammetric user new possibilities of taking images in an easier and cheaper way.

Such cameras combine the operational ease and flexibility of the ordinary amateur cameras with the metric aspects of the classical photogrammetric cameras.

The restitution phase, of course, needs special software for the real-time correction of the plate coordinates, according to the values of the calibrated position of the reseau crosses.

Every analytical plotter can manage such images, provided that a special program is available for this purpose.

However, the cost of an analytical plotter and

the complexity of its sophisticated procedures could cancel the advantage of using the low cost and simple semi-metric images.

According to this philosophy, small organisations or single researchers in particular, require a cheap user friendly instrument able to carry out all the photogrammetric functions in a rigorous but simple way.

A very recent instrument of this type was presented a few months ago by GALILEO SISCAM, the main Italian manufacturer of photogrammetric instruments.

A complete package of photogrammetric programs, including the procedures for a general use of semimetric images, has been developed and tested in cooperation with the researchers of the Politecnico di Torino, Dipartimento di Georisorse e Territorio<sup>1)</sup>.

This paper describes the hardware and

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software performances of the instrument, called STEREOBIT/20.

## 2. THE NEW "STEREOBIT/20"

Some years ago GALILEO SYSCAM presented a low cost, simplified analytical stereoplotter, called STEREOBIT, where x- and y-parallaxes were manually eliminated by the operator and a Personal Computer gave the XYZ ground coordinates of the collimated points in real time.

A new version of this instrument was produced only a few months ago, giving the STEREOBIT the full performances of an analytical plotter, at less than 1/4 of the price of the analytical instruments available on the market.

### 2.1 Description

The instrument is based on the "Inghilleri" principle [1974]: the differential x- and y-parallaxes are directly controlled by the

computer, by means of only two stepping motors, instead of the four movements usually controlled in most analytical instruments.

The analytical bases are summarized in the next section.

First let's look at the hardware scheme of the instrument (fig. 1).

A main carriage (1) is moved directly by the operator for quick movements or by a pantograph (2) for more accurate collimations.

The floating mark is obtained by stereoscopic observation, through the stereoscope (3), of the marks engraved on two glass plates (4) superimposed onto the photographs.

A secondary carriage (5) moves along x and y directions, allowing differential movements of the left image. Such movements can be driven directly by handwheels (6) or controlled by the computer.

In both cases they are transmitted to the carriage by two small stepping motors.

The size of the plate holders permits the observation of the aerial photos 9"x 9" and, obviously, of all the smaller formats of the terrestrial camera images.

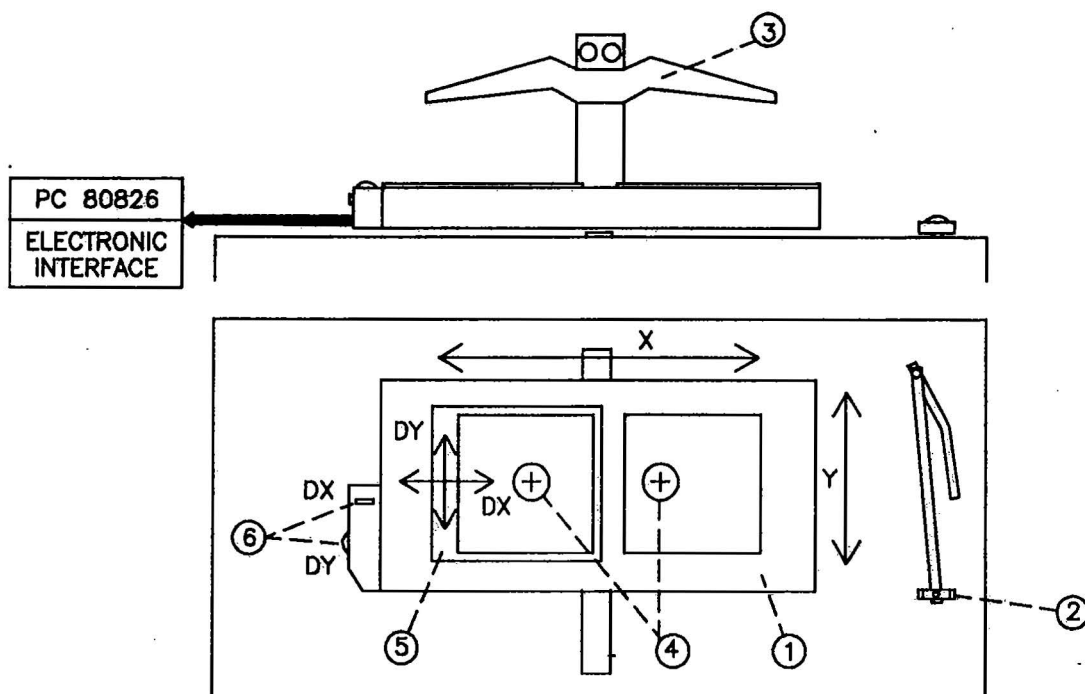


Figure 1 - The STEREOBIT/20

A double illumination device permits the use of both film or paper print photographic material.

The standard magnification of the optics is 5.5x. The resolution of the four encoders (X, Y, DX, DY) is 0.01 mm.

The standard computer is the well known IBM 80286 PC-DOS computer (or compatible), with 80287 co-processor, 640 Kbytes of RAM and a 30 Mb hard-disk. A mouse (or tablet) is suitable for managing menus and programs.

The operating system must be at least MS-DOSv.3.3.

Programs are written in BASIC or FORTRAN languages.

## 2.1 Analytical bases

One supposes that a preliminary phase of exterior orientation has already given the orientation parameters of the two photographs, i.e.:

- $XC_1, YC_1, ZC_1$  ground coordinates of the projection centers.
- $B(\omega_1, \phi_1, k_1)$  orientation matrices of the two cameras.

Let  $B_x, B_y, B_z$  and  $C_x, C_y, C_z$  be the 3 columns of these matrices.

The restitution is based on the following procedures.

### a) Single point restitution

This consists of the y-parallaxe elimination, i.e. on the control of the DY stepping motor.

The elementary problem is: given the image coordinates  $x_2, y_2$  of a point in the right plate and  $x_1$  being that of the corresponding point in the left plate, calculate  $y_1$  and correct the y-parallaxe by means of the DY motor.

For the solution, in the real time cycle, the computer determines:

- the internal direction tangents  $tx_1, tx_2, ty_2$
- the external, transformed direction tangents of the right image, obtained by rotating the internal direction tangents:

$$TX_2 = \frac{\begin{vmatrix} tx_2 & ty_2 & 1 \\ tx_1 & ty_1 & 1 \end{vmatrix} C_x}{\begin{vmatrix} tx_2 & ty_2 & 1 \\ tx_1 & ty_1 & 1 \end{vmatrix} C_z}$$

$$TY_2 = \frac{\begin{vmatrix} tx_2 & ty_2 & 1 \\ tx_1 & ty_1 & 1 \end{vmatrix} C_y}{\begin{vmatrix} tx_2 & ty_2 & 1 \\ tx_1 & ty_1 & 1 \end{vmatrix} C_z}$$

- the  $ty_1$  direction tangent, using the parallaxe equation
- and finally  $y_1 = -p \cdot ty_1$ .

Comparing the so computed  $y_1$  with the  $y_1^*$  read on the left plate at the moment, the difference  $dy = y_1 - y_1^*$  can be evaluated and corrected by the DY stepping motor.

### b) Contours

During the restitution of the contour lines, the computer must control both the DX and DY movements.

Given  $x_2, y_2$  and having prefixed the height  $Q_c$  of the contour, one needs to calculate  $x_1, y_1$  and determine the DX, DY movements.

The solution is achieved by computing:

- the direction tangents  $tx_2, ty_2, Tx_2, TY_2$  as in the single point mode
- the actual height  $ZC_2$  of the collimated point P and the difference  $DZ_2 = Q_c - ZC_2$
- the ground coordinates of:

$$XP = XC_2 + TX_2 \cdot DZ_2$$

$$YP = YC_2 + TY_2 \cdot DZ_2$$

- this ground point can be "projected" to the left plate:

$$TX_1 = \frac{XP - XC_1}{QP - ZC_1}$$

$$TY_1 = \frac{YP - YC_1}{QP - ZC_1}$$

- having called  $c = C^T$  the transposed orientation matrix and  $cx, cy, cz$  its columns, one obtains:

$$x_1 = -p \frac{\begin{vmatrix} TX_1 & TY_1 & 1 \\ tx_2 & ty_2 & 1 \end{vmatrix} cx}{\begin{vmatrix} TX_1 & TY_1 & 1 \\ tx_2 & ty_2 & 1 \end{vmatrix} cz}$$

$$y_1 = -p \frac{\begin{vmatrix} TX_1 & TY_1 & 1 \\ tx_2 & ty_2 & 1 \end{vmatrix} cy}{\begin{vmatrix} TX_1 & TY_1 & 1 \\ tx_2 & ty_2 & 1 \end{vmatrix} cz}$$

- the difference to the read coordinates is then sent to the stepping motors DX, DY.

Both the above computation sequences are carried out in less than 20 milliseconds and

therefore the operator can explore the model in an apparently continuous stereoscopic way.

There is no problem, therefore, for plotting edge lines or contours: the real time cycle and the computer control of the motors guarantee a correct continuous solution.

The ground coordinates of the points are computed and can be recorded for an efficient data collection.

### 3. OVERVIEW OF THE SOFTWARE

A large amount of photogrammetric software is available on the STEREOBIT/20, derived from the wide software library of the Galileo analytical plotter "DIGICART".

Five packages are of special interest in particular for most architectural applications as shown in fig. 2:

- 1 - Metric images ("RESTI")
- 2 - Semi-metric images ("RESEAU/ROLLEI")
- 3 - Quasi-metric images ("RESEAU/PENTAX")
- 4 - Aerial triangulation
- 5 - Off-line graphic editing

An efficient triangulation procedure (point 4) has been developed for data collection and block adjustment up to 100 models.

In addition to the above routines, many other programs are available for a wide series of applications.

For example:

- a self-explaining program has been developed by GALILEO for teaching and training purposes.
- a simple but efficient package is also available for collecting and editing data for the information systems.

In particular, the produced files are in DXF format (compatible to Auto-Cad) or in a simpler Galileo format for further data-base management system programs (for instance: GART, especially designed for architectural applications).

In every case, all the selections of the wanted program or procedure are obtained by the user-friendly "pop-up menus" technique.

The operator will be able to select the chosen option by using the UP-DOWN cursor key, or by pushing the left key of the mouse; some options, when selected, display further

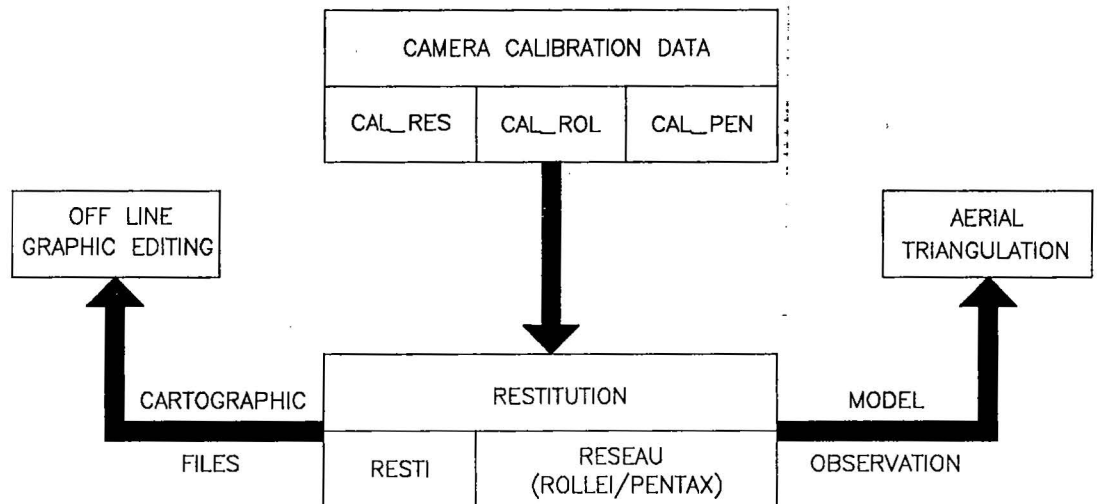


Figure 2 - STEREOBIT/20: available restitution procedures

A procedure for "self-calibration" of non metric cameras will be available within a few months.

sub-menus for a more precise choice.

For example, each of the options 1, 2 or 3 (see above) opens a sub-menu that offers two possibilities: CAMERA CALIBRATION DATA or

## RESTITUTION.

By selecting the CAMERA CALIBRATION DATA option, the operator is allowed to load the data of the camera, as described in the calibration certificate: principal distance, principal point position, fiducial point coordinates, lens distortion table and (in case the camera is semi-metric) the coordinates of the calibrated reseau.

The option "RESTITUTION" permits the choice of the wanted procedure: metric (RESTI), semi-metric (ROLLEI) or quasi-metric (PENTAX) image restitution.

Flow-charts in figures 3 and 4 show how the different restitution phases are carried out. The restitution package for quasi-metric images is, in particular, described in chapter 5.

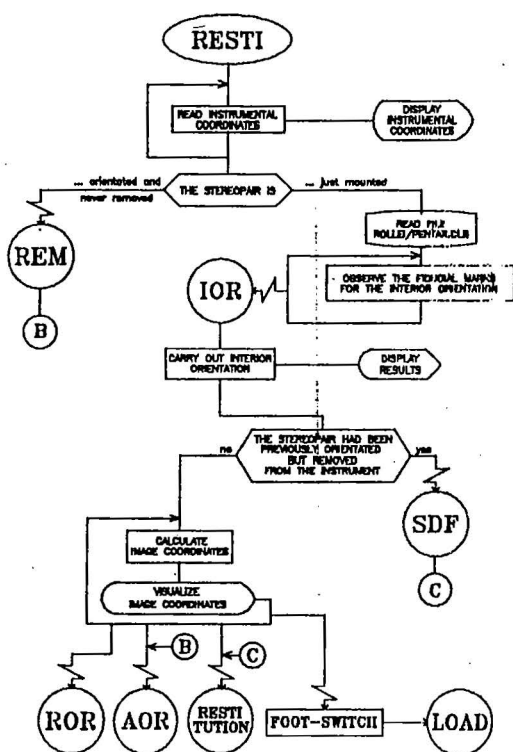


Figure 3 - The RESTI package flow-chart

Pop-up menus, divided into omogeneous functions (EDIT, ORIENTATION, OUTPUT, RESUME, END OF JOB, AERIAL TRIANGULATION, etc.) gives the operator an easy guide through the successive restitution phases.

A help menu allows one to display all the

commands and gives a short comment for each.

Each selected command causes the interruption of the stand-by cycle of the computer and starts the corresponding procedure.

In the flow-charts such interruptions are graphically represented by a small broken arrow.

## 4. RESEAU CALIBRATION THEORY AND PROCEDURES

It is known that, among the various elementary plane transformations, a particular affinity, called general affine transformation and a particular projectivity called homography, exist.

If oxy and OXY are two plane reference systems, the general affine transformation allows one to transform exactly three known points of the first system into three corresponding points of the second system.

The homography allows one to transform four points from the first to the second system.

Therefore, the general affine transformation allows one to change any triangle into any other and the homography allows one to transform a quadrilateral into any other.

Analytically, the equations of the general affine transformation are:

$$\begin{aligned} X &= ax + by + c \\ Y &= dx + ey + f \end{aligned}$$

and the homographic transformation equations are:

$$\begin{aligned} X &= \frac{ax + by + c}{gx + hy + 1} \\ Y &= \frac{dx + ey + f}{gx + hy + 1} \end{aligned}$$

When the 6 parameters (a,...,f) of the general affine transformation or the 8 parameters (a,...,h) of the homography are known, the calculation of the transformed coordinates (X,Y), given (x,y), is immediate.

In both cases, the parameters, originally unknown, can be defined by the knowledge of

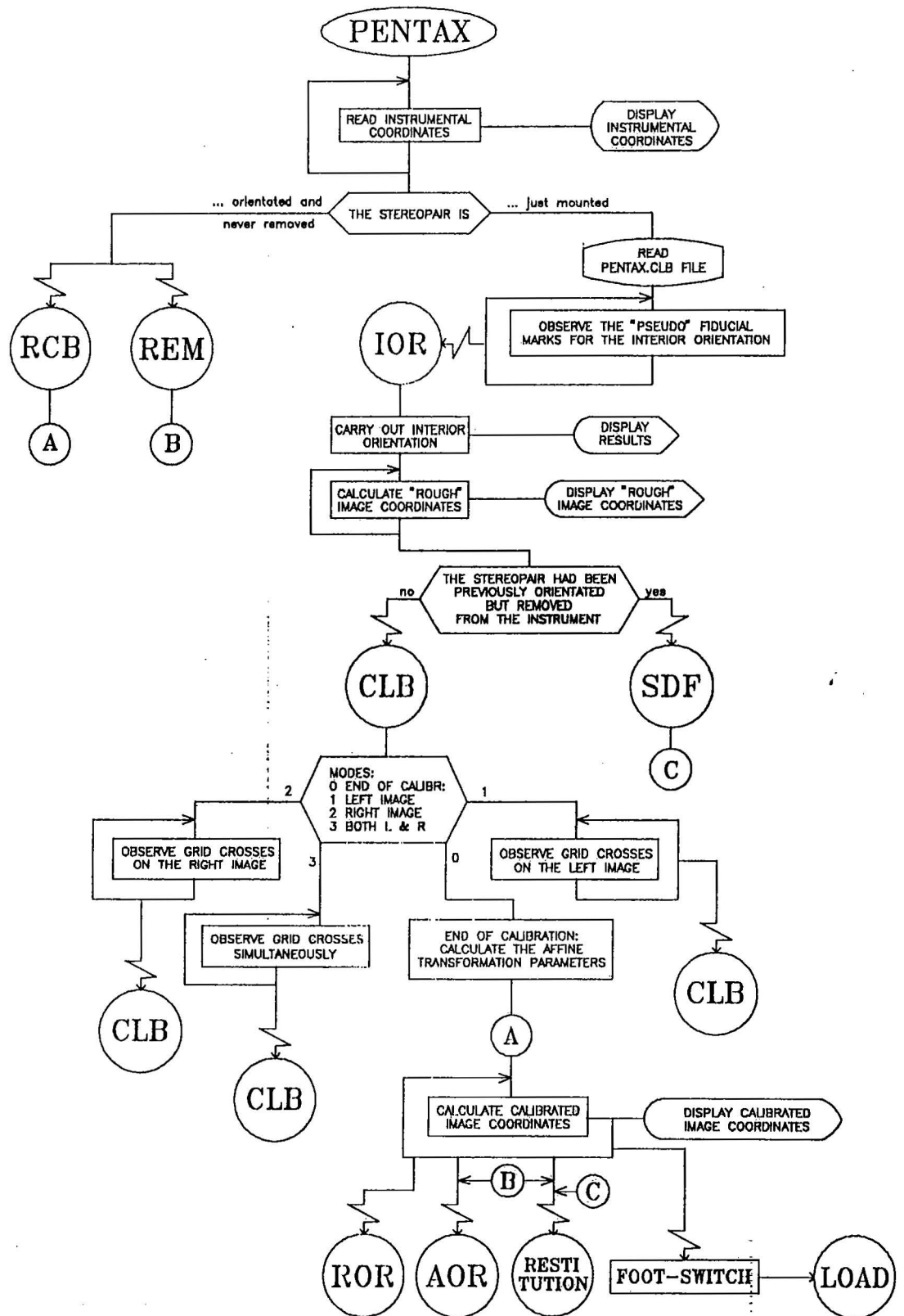


Figure 4 - The PENTAX package flow-chart

the coordinates of some points in the two referencesystems.

As a minimum, six equations (2x3 known points) of type a), or eight equations (2x4 known points) of type b) can be written, where the unknowns are the above mentioned parameters.

Equations a) or b) have a particular geometrical meaning: the transformation from the starting configuration (oxy system) to the final configuration (OXY system) can be seen as the combined result of:

- for the general affine transformation: 2 translations, 1 rotation, x- and y-scale change and 1 tilt as shown in fig. 5;

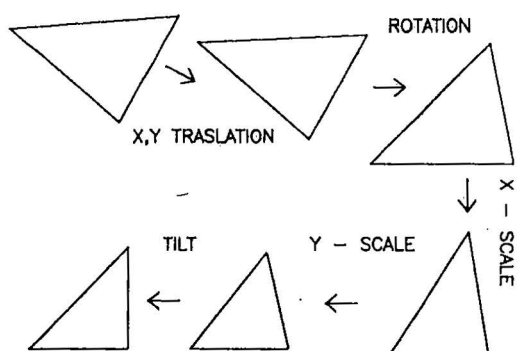


Figure 5 - Parameters of the general affine transformation

- for the homography: 2 traslations, 1 rotation, x- and y-scale change, 1 tilt and 2 angular convergences as shown in fig. 6.

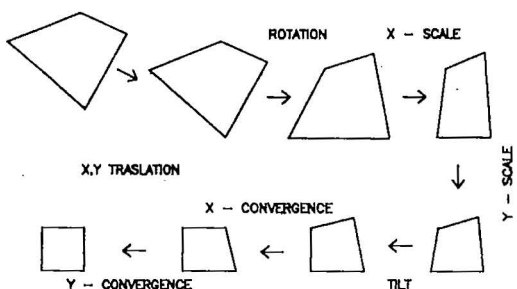


Figure 6 - Parameters of the homographic transformation

In both cases it is simple to express the numerical values of these entities in function of the mathematical parameters which define the above mentioned transformations (a,...,f or a,...,h).

What has all this to do with our problem?

Let us consider a mesh of the calibration grid that appears on the photogram and which we can see as being very deformed.

If we used a Pentax camera with a 9 cross grid, the image area can be subdivided into 8 triangular meshes, as shown in fig. 7).

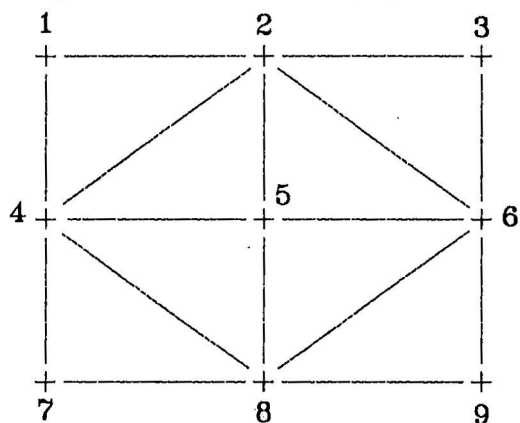


Figure 7 - PENTAX grid and triangular subdivision

If the camera is a Rollei camera with a 121 cross reseau, the photogram is subdivided into quadrilaterals, as shown in fig. 8).

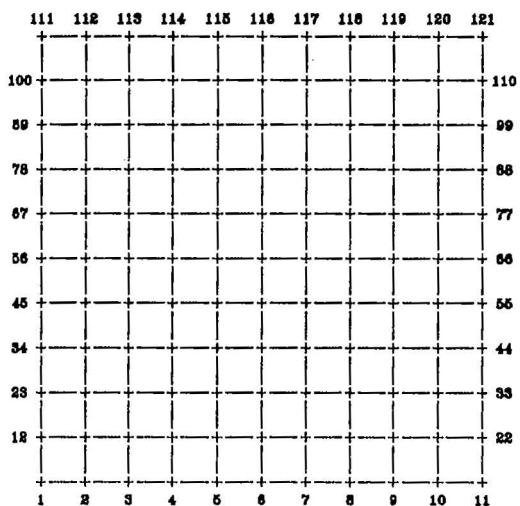


Figure 8 - ROLLEI grid and quadrangular subdivision

It is possible to calculate the parameters of the affine general transformation or of the homography that transform the vertices of each triangular or quadrangular mesh from system (x,y) to (X,Y) and apply the same transformation to all the internal points of the considered mesh.



It can seem arbitrary to model the complex deformations of the photogram by a simple affine or homographic transformation: the small size of the mesh (5x5 mm for the Rollei, 23x17 mm for the Pentax camera) and some properties of the considered transformations, lead us to think that the phenomenon has been well described and corrected.

This approach seems to be sufficiently rigorous: many of the commonly used correction systems are limited to a linear interpolation or to attribute the simple translation of the nearest cross to each point.

## 5. THE SOFTWARE PACKAGE FOR QUASI-METRIC CAMERAS

We have already pointed out that:

- there exist a new type of camera, that we have called "quasi-metric", (ref. also to COMOGLIO [1991]), produced by PENTAX and equipped with a flattening device and a reseau of only 9 crosses.
- a package for the restitution of such images has been developed, based on the affine transformation and a triangular subdivision of the image area, as shown in fig. 7.

We now want to give a short description of this package, called PENTAX (see flow-chart fig.4).

When starting the procedure, the operator is required to input some general information and the calibration data file of the camera, previously edited and recorded on the disk.

Then, the program asks the operator if he is going to work on a stereopair already positioned on the instrument and never previously moved (as in the case where the job has been interrupted and then restarted) or if it has just been mounted at that moment.

In the first case, after the collimation of the start-points, the operator must select the MODEL RESUME command of the RESUME menu; in this way he can restart his job from the previous interruption point, by-passing all the preliminary calibration and orientation phases.

Otherwise, the procedure starts with the collimations necessary for the internal orientation. By using four crosses of the reseau as fiducial marks, a preliminary "rough" interior orientation is carried out.

The grid calibration procedure is then activated: the operator collimates all the reseau

crosses that he sees in the 2 photograms. During this acquisition phase, a scheme of the two reseau appears on the screen, allowing the operator to follow his work and avoiding any collimations being forgotten.

When all the collimations are carried out, the program calculates and stores in memory the parameters of the 8 (left image) + 8 (right image) general affine transformations.

The instrument is then ready to start restitution: the image coordinates of the observed points will be measured and then continuously corrected, by means of the affine general transformation. The logical sequence of the real time operations is:

- the encoders give the 4 "instrument coordinates" of the 2 collimated points;
- the program finds (separately for the left and for the right photogram) the meshes in which the collimated points are located;
- the 6 parameters of the affine transformation corresponding to the particular meshes are retrieved from memory and the instrument coordinates transformed into the corrected coordinates;
- after this correction, the instrument will operate as if metric images were used.

Therefore, after the grid calibration phase, the PENTAX program is exactly the same as the standard RESTI program: the operator goes on with the usual relative and absolute orientation phases etc., following the classical procedures of the restitution programs.

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