ANALYTICS IN NON-TOPOGRAPHIC PHOTOGRAMMETRY

W. Wester - Ebbinghaus

Institut für Photogrammetrie u. Bildverarbeitung
der Technischen Universität Braunschweig
Gaußstraße 22, 3300 Braunschweig
Federal Republic of Germany

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Abstract

The paper describes possibilities and procedures for the
analytical restitution of photogrammetric images, encluding
strategies for simultaneous determination of the image space
parameters. The orientation of small format matrix-sensors is
especially taken into account.

Introduction

The analytical formulation and numerical realization of image
restitution has encreased the possibilities of photogrammetry
very much:

The photogrammetric parameters can be choosen according to the
situation on site, without restrictions caused by the limited
possibilities of the camera and the restitution procedure.

Recently developed recording techniques, analogue photography
as well as electronic digital imaging, can be applied to photo-
grammetry, enlarging the possibilities especially in non-topo-
graphic applications.

By means of a general analytic formulation, the given non-photo-
grammetric information can be used simultaneously in the photo-
grammetric restitution process. The combined adjustment of
photogrammetric and non-photogrammetric information offers best
possible preconditions for precision and reliability.

1.   Bundle orientation

1.1.   Photogrammetric bundles

The simultaneous orientation of all the bundles given in a photo-
grammetric network (fig. 1) is the basic procedure in non-topo-
graphic photogrammetry (bundle adjustment). According to fig. 2
equations 1 describe the photogrammetric information, that are
the measured image coordinates, as a function of the unknown
object coordinates and the orientation parameters. This leads
to a redundant system which allows to determine the unknown
parameters by means of least square adjustment: The object
coordinates and the orientation parameters in object
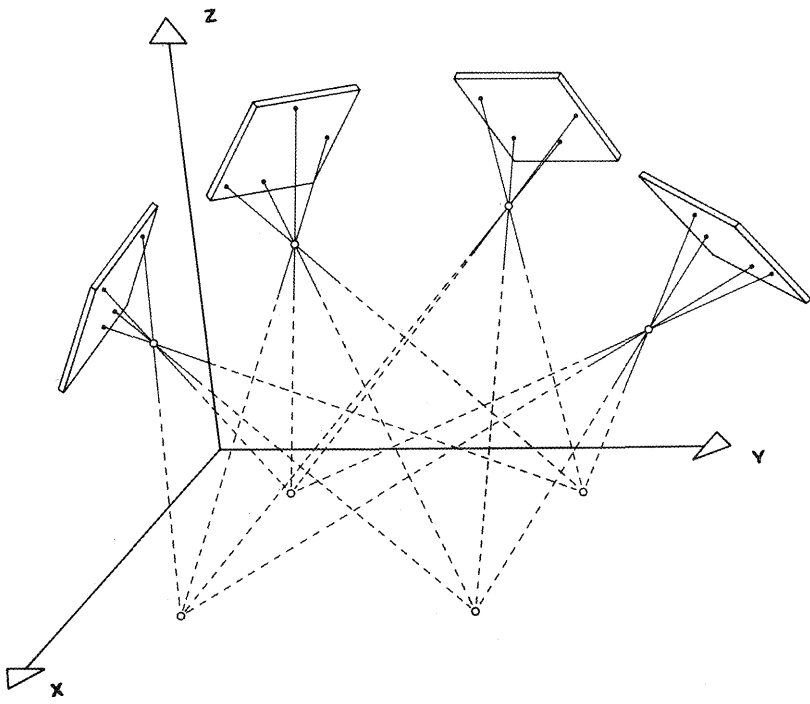
Fig. 1   Multi-Image-Triangulation
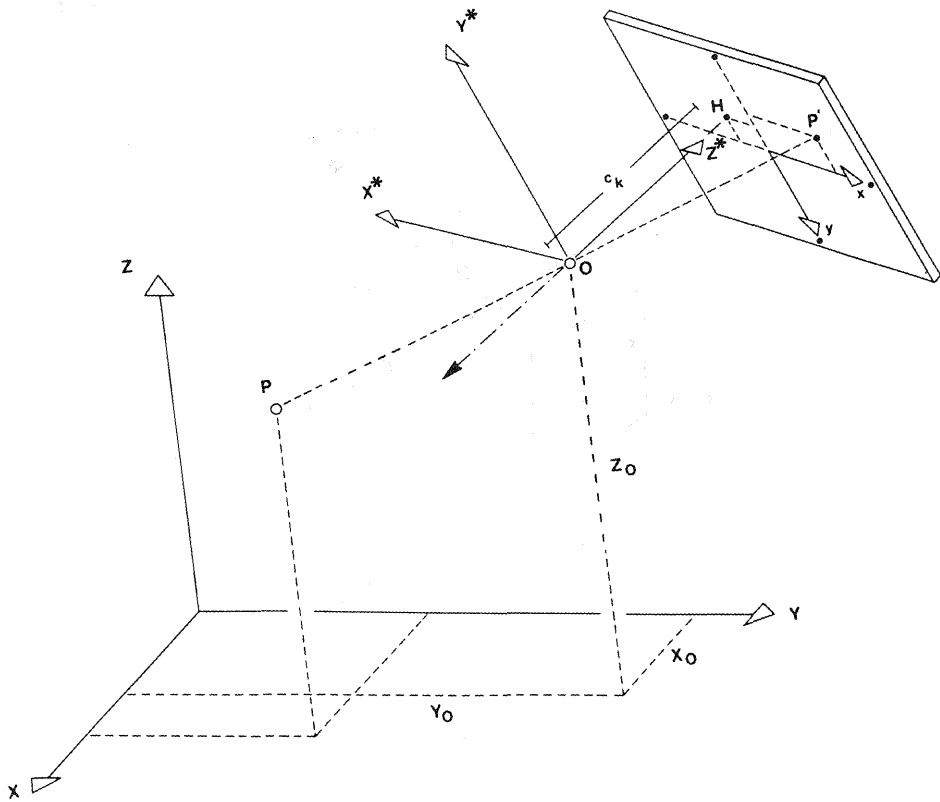

Fig. 2   Definition of a photogrammetric direction
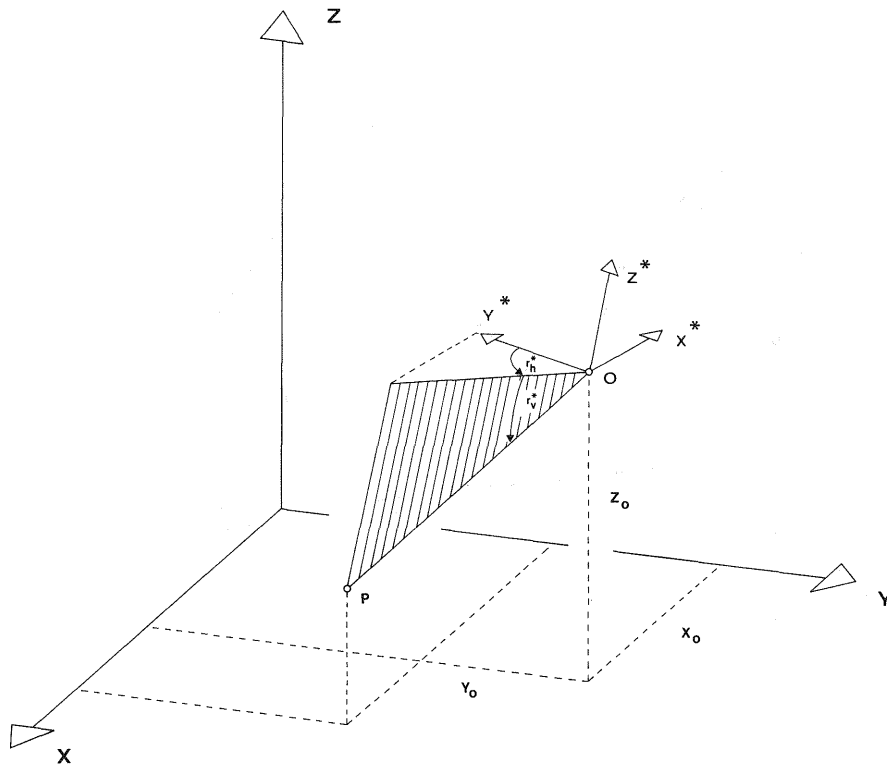
Fig. 3   Definition of a direction measured with a theodolite
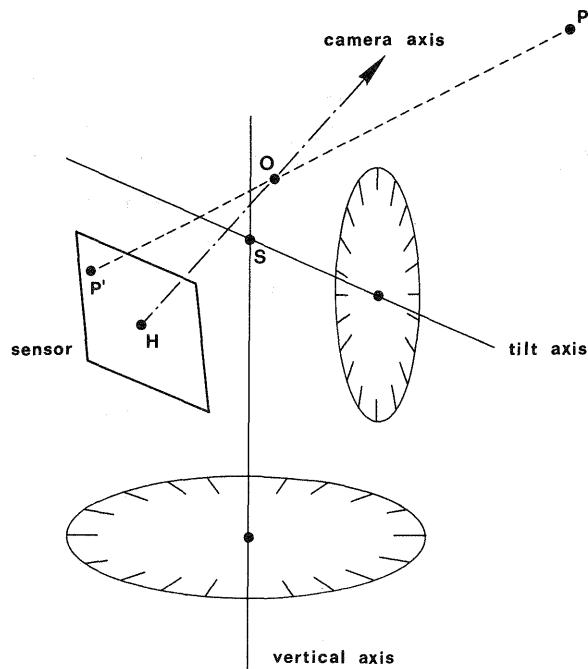

Fig. 4   CCD-matrix-sensor integrated into the telescope
           of a electronic theodolite

and image space are determined in order to fit the bundles
of rays, which are defined by the object points and the
perspective centres, to the measured image points in the best
possible way, following the restriction that the square sum
of the deviations between the projected and the measured
image points has to be minimal (Wolf 1975, Wong 1975, Hell
1979, El-Hakim 1982, Wester-Ebbinghaus 1985).

The photogrammetric network may be adjusted free, using
only the measured image coordinates, or restricted,
orientating the model absolutely in object space by means
of additional control information (Zinndorf 1985, Papo 1986,
Fritsch 1986, Koch 1988).

1.2.   Bundles measured with a theodolite

According to fig. 3, equations 2 formulate the horizontal
and vertical directions r_h^* and r_v^*, measured with a theodolite,
as a function of the object coordinates and the orientation
parameters of the theodolite axes. By these means, bundles
measured with a theodolite can be introduced into bundle
adjustment (Wester-Ebbinghaus 1985).

Similar to chapter 1.1 the parameters are determined, mini-
mizing the deviations between the measured directions r_h^* and
r_v^* and those, projected by means of the equations 2.

If the instrument was levelled or if the direction of the
vertical axis was measured on-site (Elmiger and Meyer 1981),
ω and φ may be introduced as additional observations (Wester-
Ebbinghaus 1985).

1.3.   Bundles measured with a video-theodolite

With a CCD-matrix sensor, integrated into the telescope of a
motorized electronic theodolite (fig. 4), it is possible to
measure the rays automatically (Gottwald and Berner 1987,
Wester-Ebbinghaus 1988, b). The theodolite needs to be
directed towards the object point only approximately, just
to make the target appear inside the frame of the matrix
sensor (fig. 5). In order to introduce the measurements into
bundle adjustment, equations 3 describe the image coordinates
x, y as a function of the orientation parameters of the
theodolite axes in the object coordinate system, the measured
directions r_h^*, r_v^* and the parameters describing the orientation
of the matrix sensor system in the system of the theodolite
axes. X_O, Y_O and Z_O are the object coordinates of S, the
centre of the theodolite axes. In order to describe the
situation generally, the vertical axis Z_T^* of the theodolite
is not considered to be vertical orientated rigorously. Y_T^*
defines the horizontal and vertical zero direction. In order
to move the instrument into the recording position, the
theodolite is first turned horizontally by r_h^* around Z_T^*,
transferring X_T^* to $\tilde{X}$, and then tilted by r_v^* around $\tilde{X}$, trans-
ferring Y_T^* finally to $\tilde{Y}$. Vector $\vec{r}_O$ is defined between S and
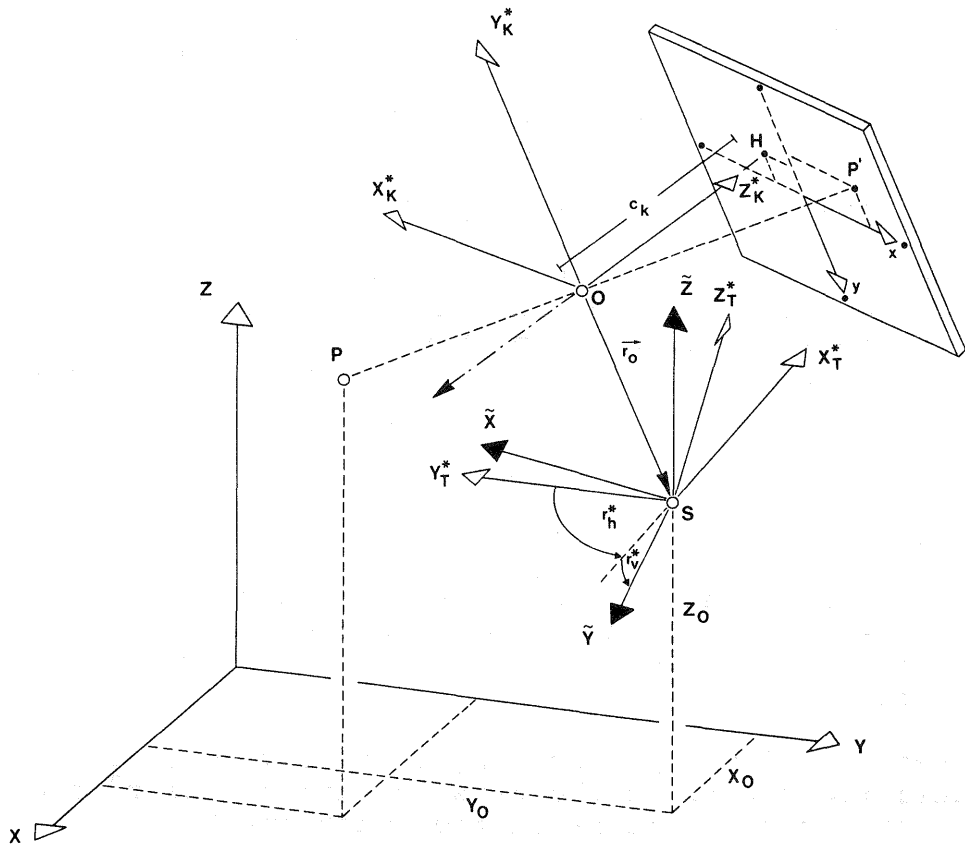the perspective centre O.

Fig. 5   Definition of a direction measured with a video-
          theodolite
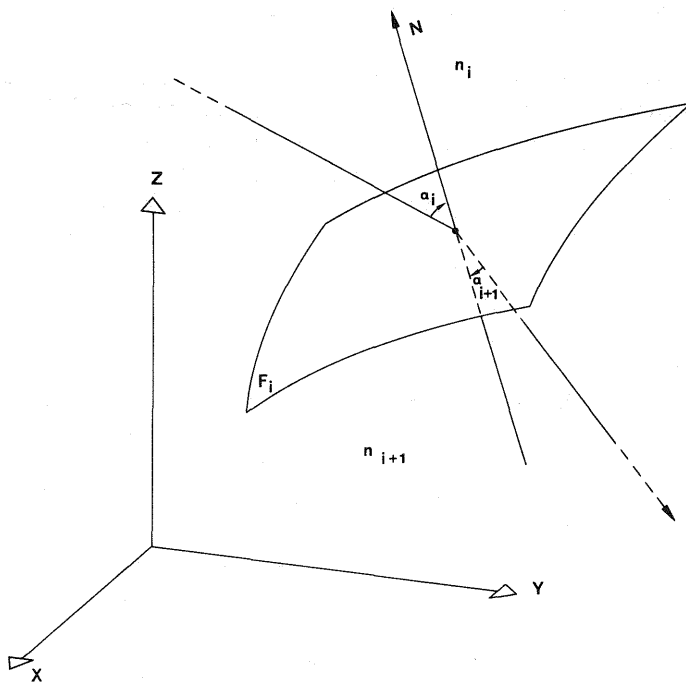

Fig. 6   Refracting surface in a bundle of rays,
          Multi-Media-Photogrammetry by rigorous
          ray tracing (Kotowski 1987 and 1988)

1.4. Alternative parameters for the orientation of bundles of rays

Hinsken (1987, 1988) presented an algorithm, which allows the spatial orientation of bundles of rays without predefining initial values, the algebraic rotation parameters are derived from a formulation, Pope presented 1970. The algorithm is very well suited to realize a step wise orientation strategy in order to determine initial values for the parameters of the bundle adjustment. The bundle adjustment itself, also formulated by these alternative parameters, proved to converge in a robust and rapid way.

2. The photogrammetric camera

2.1. Correction of film deformations by means of réseau technique

Réseau cameras have become very important in non-topographic photogrammetry. In addition to high precision large format cameras (13 x 18 cm^2 - 23 x 23 cm^2) like Zeiss Jena UMK and GSI CRC1 (Fraser and Brown 1986) with mechanical film flatening, small format cameras (6 x 6 cm^2 - 2,4 x 3,6 cm^2) like Hasselblad MK70/MKW, Rolleimetric 6006/3003 and Leitz Elcovision, equipped with a glas réseau plate for numerical correction of film-deformation, allow to use professional photo technique for photogrammetry. Conventional terrestrial photogrammetric medium format cameras (6 x 9 cm^2 - 9 x 12 cm^2) like Wild P31/P32 and Zeiss Oberkochen TMK/SMK, mainly designed for the use of photo plates, dissappeared from the market.

Kotowski (1984) presented a flexible analytical procedure for the correction of film deformations by means of réseau information. A synthetic regular interpolation grid is derived from the deformation, determined at the réseau points, which may be measured in non-regular distribution. The procedure is similar to strategies for object hight interpolation in topographic photogrammetry, using finite elements (Ebner 1983).
In order to carry out a least square adjustment, the deformation measured at the réseau points is described as a function of the deformation to be determined at the grid points, using bi-linear interpolation. Continuity between adjoining meshes is realized by additional observations, defining the degree of restriction by a suitable observation weight.

2.2. Analytical camera calibration

In non-topographic applications with convergent photographs and spatial object range, often it is not possible to define the image space parameters instrumentally and to calibrate the camera in advance.

The image space parameters can be treated as unknowns within the bundle adjustment, if the photogrammetric net work is
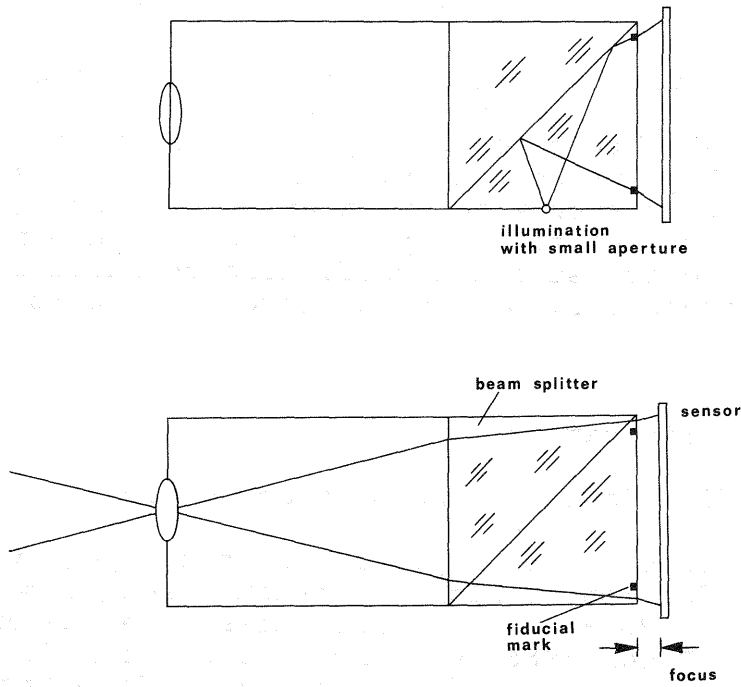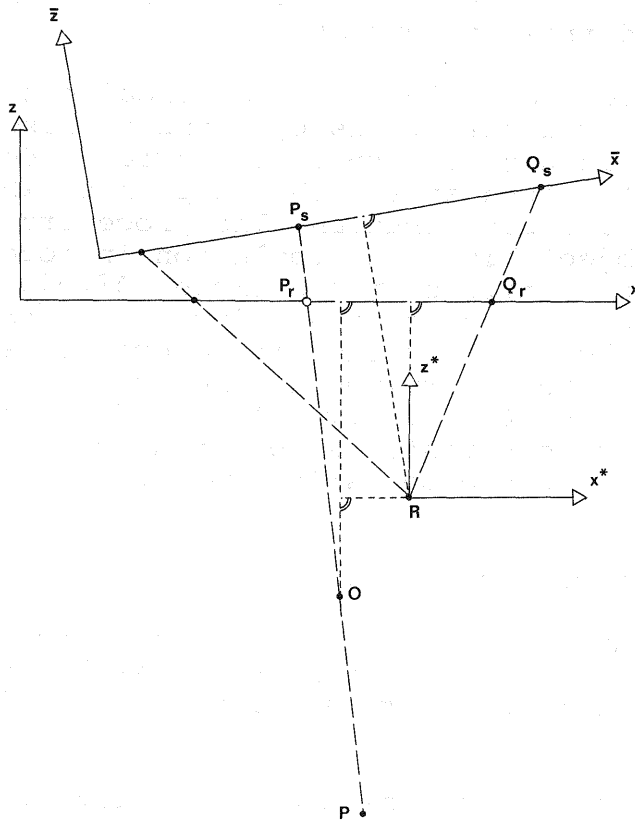
Fig. 7   Focusable CCD-video-camera with fiducial marks

Fig. 8   Orientation of a matrix-sensor in image space
            by means of fiducial marks projected with a
            seperate illumination source

designed in a suitable way, supported by additional geometric
information in object space if necessary. A comprehensive
description of typical schemes for camera calibration, simul-
taneously carried out within bundle adjustment, was presented
by Wester-Ebbinghaus (1988 a).

By means of simultaneous camera calibration the photogrammetric
net can be restituted in the best possible way, making use of
the measured image information independent from instrumentally
defined, pre-determined parameters.

3.   CCD-matrix-sensors in the photogrammetric recording system

3.1.   Metric CCD-video-camera

CCD-matrix-sensors in principle are suitable for photogrammetric
applications. The solid state surface offers the geometric
preconditions for the recording of digital images on-site,
which allow photogrammetric restitution on-line.

The image transfer of conventional television technique how-
ever provides digital images with considerable geometric defor-
mations, mainly the so called line-jitter (Beyer 1988), affine
deviation between the x- and y-coordinates and shift of the
image reference system. While line-jitter can be corrected
electronically by means of external synchronisation, (Wester-
Ebbinghaus 1988 b), affine deformation and shifting of the
image reference system can be adjusted photogrammetrically,
by projecting fiducial marks onto the sensor (fig. 7).

Using a special illumination with small aperture, the fiducial
marks are projected with great depth of sharpness. Therefore
the camera can be focused for every single object point,
shifting the sensor perpendicularly to the fiducial plane;
by reprojecting the individually focused images into the
fiducial plane by means of the fiducial marks, all the
recorded object points are finally defined in the same image
plane with constant image space parameters.

The perspective relation between the fiducial illumination
source and the fiducial marks can not be considered to
correspond exactly to the perspective relations between the
centre of the object recording and the fiducial marks. There-
fore the orientation and the reprojection of the images has
to be carried out in seperated steps, distinguishing between
the centre of fiducial projection and the centre of object
recording.

In fig. 8 O is the projection centre of the object recording
and R the illumination source for the fiducial projection.
Equations 4 describe the coordinates of the fiducial mark Q_r
in the fiducial plane x,y as a function of the coordinates
of the projected fiducial mark Q_s in the sensor system

$\overline{x}, \overline{y}, \overline{z}$, the orientation parameters of x^*, y^*, z^* in the sensor system $\overline{x}, \overline{y}, \overline{z}$ and the coordinates of R in the fiducial system x, y, z. By means of equations 4 the orientation of x^*, y^*, z^* in $\overline{x}, \overline{y}, \overline{z}$ can be determined using at least four fiducial marks.

By means of the equations 5 the image point P_S in the sensor system $\overline{x}, \overline{y}, \overline{z}$ is transferred to P_r in the fiducial plane x, y: after P_S is transformed from $\overline{x}, \overline{y}, \overline{z}$ into x^*, y^*, z^* by means of the orientation parameters of x^*, y^*, z^* in $\overline{x}, \overline{y}, \overline{z}$, determined by the equations 4, x^*, y^*, z^* is translated from R to O in order to carry out the central projection of P_S into P_r with respect to O, using the coordinates of O in the fiducial system x, y, z.

3.2   Réseau-scanning-camera

A réseau-scanning-camera allows high resolution digital object recording by means of sequentially recorded large scale partial images, shifting an matrix-sensor in the image plane of a photogrammetric camera. The orientation of the partial images in the image space of the camera is realized optic-numerically by means of a réseau plate in the image plane (Luhmann and Wester-Ebbinghaus 1987, Riechmann 1988).

The focusing, the orientation and the projection of CCD-images, described in chapter 3.1, can be applied to réseau-scanning as well, using the four points of the réseau meshes as fiducial marks for the partial images concerned.

Conclusions

The paper tried to point out some aspects of the state-of-the art in analytical non-topographic photogrammetry, basic formulations which are already used in operational systems as well as recent developments for systems to be realized in the near future.

Electronic matrix-sensors, providing digital images on-site, offer exciting new applications for non-topographic photogrammetry, but they need special analytical solutions in order to use these new potentials consequently.

$$\begin{bmatrix} X^* \\ Y^* \\ Z^* \end{bmatrix} = D(\omega, \varphi, x) \cdot \begin{bmatrix} X - X_O \\ Y - Y_O \\ Z - Z_O \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \end{bmatrix} = \frac{-c_k}{z^*} \cdot \begin{bmatrix} X^* \\ Y^* \end{bmatrix} + \begin{bmatrix} x_H + dx \\ y_H + dy \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} X^* \\ Y^* \\ Z^* \end{bmatrix} = D(\omega, \varphi, x) \cdot \begin{bmatrix} X - X_O \\ Y - Y_O \\ Z - Z_O \end{bmatrix} \qquad (2)$$

$$r_h^* = \arctan \frac{X^*}{Y^*} \qquad\qquad r_v^* = \arctan \frac{Z^*}{\sqrt{X^{*2} + Y^{*2}}}$$

$$\begin{bmatrix} x_{Q_S}^* \\ y_{Q_S}^* \\ z_{Q_S}^* \end{bmatrix} = D(\omega, \varphi, r,) \cdot \begin{bmatrix} \overline{x}_{Q_S} - \overline{x}_R \\ \overline{y}_{Q_S} - \overline{y}_R \\ - \overline{z}_R \end{bmatrix} \qquad (4)$$

$$\begin{bmatrix} x_{Q_r} \\ y_{Q_r} \end{bmatrix} = \frac{z_R}{z_{Q_S}^*} \cdot \begin{bmatrix} x_{Q_S}^* \\ y_{Q_S}^* \end{bmatrix} + \begin{bmatrix} x_R \\ y_R \end{bmatrix}$$

$$\begin{bmatrix} x^*_{P_S} \\\\ y^*_{P_S} \\\\ z^*_{P_S} \end{bmatrix} = D(\omega, \varphi, \varkappa) \cdot \begin{bmatrix} \bar{x}_{P_S} - \bar{x}_R \\\\ \bar{y}_{P_S} - \bar{y}_R \\\\ - \bar{z}_R \end{bmatrix}$$

(5)

$$\begin{bmatrix} x_{P_r} \\\\ y_{P_r} \end{bmatrix} = \frac{z_O}{z^*_{P_S} - z^*_O} \cdot \begin{bmatrix} x^*_{P_S} - x^*_O \\\\ y^*_{P_S} - y^*_O \end{bmatrix} + \begin{bmatrix} x_O \\\\ y_O \end{bmatrix}$$

$$\begin{bmatrix} X^*_T \\\\ Y^*_T \\\\ z^*_T \end{bmatrix} = D(\omega, \varphi, \varkappa) \cdot \begin{bmatrix} X - X_O \\\\ Y - Y_O \\\\ Z - Z_O \end{bmatrix}$$

$$\begin{bmatrix} \tilde{X} \\\\ \tilde{Y} \\\\ \tilde{Z} \end{bmatrix} = D(r^*_h + dr^*_h, r^*_v + dr^*_v) \cdot \begin{bmatrix} X^*_T \\\\ Y^*_T \\\\ z^*_T \end{bmatrix}$$

(3)

$$\begin{bmatrix} X^*_K \\\\ Y^*_K \\\\ z^*_K \end{bmatrix} = D(\omega_O, \varphi_O, \varkappa_O) \cdot \begin{bmatrix} \tilde{X} & r^*_{X_O} \\\\ \tilde{Y} & + & r^*_{Y_O} \\\\ \tilde{Z} & & r^*_{Z_O} \end{bmatrix}$$

$$\begin{bmatrix} x \\\\ y \end{bmatrix} = \frac{-c_k}{z^*_K} \cdot \begin{bmatrix} X^*_K \\\\ Y^*_K \end{bmatrix} + \begin{bmatrix} x_H + dx \\\\ y_H + dy \end{bmatrix}$$

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