Orthophoto Production in the new ContextMAPPER System

Paper presented to Commission II/2, ISPRS Congress,
Kyoto, Japan, July 1988

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0. Abstract

For the last few decades, rectified images have been successfully used in photogrammetry and cartography to produce image maps (orthophoto maps) of high geometric fidelity and information content. With the growing importance of Geographic Information Systems, there is another necessity for rectification of image data.

With the ContextMAPPER system, a new photogrammetric/cartographic workstation based on a digital image processing system will be introduced. The MAPPER system enables image rectification and geocoding of different types of remote sensing data (e.g. digitized aerial photographs, LANDSAT, SPOT). Since special hardware processors are used, the system is suitable for operational applications. Finally, the capability of the system will be demonstrated by some examples.

1. Introduction

During the last 20 years, photo maps have been systematically produced as valuable supplements or economical alternatives to topographic line maps. Planers of many disciplines especially appreciate their high actuality, the full information content and the geometric accuracy. But up to now, the most used method of generating large scale orthophoto maps is by means of analytical orthophoto projectors.

Since data of remote sensing satellites became available, also small scale image maps were produced. The digital nature of these data led to the development of procedures for digital image rectification. In countries with poor map coverage, these image maps are used as substitutes for topographic line maps. Because of the different spectral bands, the data are also suitable to produce thematic maps (e.g. land use maps, geographic maps).

Due to the development of faster, less expensive computers with larger memory, also digital production of large scale orthophoto maps now becomes possible. The major advantage in comparison to analog rectification of photos is the possibility of using image processing techniques like contrast enhancement and mosaicking.

In the last few years Geographical Information Systems (GIS) have been developed which are already used in practice for small areas. It is anticipated that their distribution will rapidly grow. The combination of different types of data (e.g. raster, vector, attributes) in GIS requires that the data must be geocoded (related to a certain area within a common coordinate system). Rectification procedures for geocoding of image data have to be efficient and easy to handle since not all users of GIS are experts in photogrammetry or remote sensing.

2. General Concept of the ContextMAPPER System

The MAPPER system is a photogrammetric/cartographic workstation which is based on the Context Vision GOP302 image processing system. Fig. 1 shows an overview of the entire system.
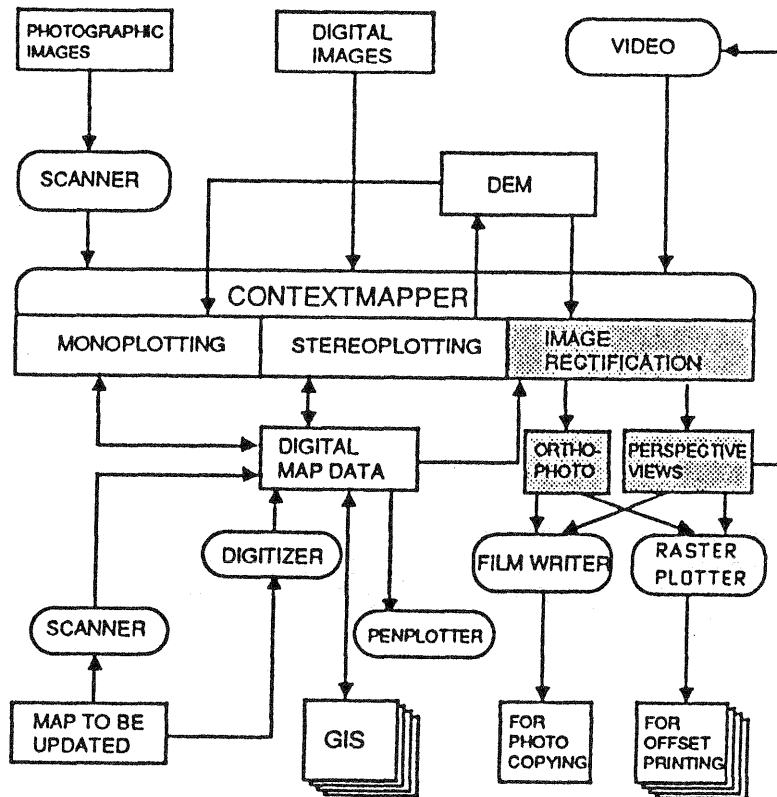

Fig. 1 : Digital Photogrammetric/Cartographic Workstation

The system includes all functions which are presently realized in analytical stereoplotters and analytical orthoprojectors. In addition, the system offers all possibilities of a sophisticated image processing system. Since the system is explained in detail in / Lohmann et al. 1988 /, this chapter only describes the integration of the rectification software into the whole system.

The modular concept enables each user to design his own system according to his special needs. Survey departments or private companies, whose tasks range from aerial triangulation up to the production of image maps and line maps might use the full equipment. The possibilities of stereoscopic evaluation of images is also interesting for engineering and industrial applications. For a user, who is mainly interested in updating line maps and who has access to Digital Terrain Models (DTM), the monoplotting module could be sufficient.

If only rectification is required, a basic system would have the following configuration :

- Sun-3 Host Processor
- Geometric Transform Processor (GTP)
- General Operator Processor (GOP)
- Image Processing Software
- Rectification Software

The basic configuration can be extended by e.g. programs for bundle block adjustment or DTM interpolation. The rectification software includes all programs that are necessary to generate geocoded images. However, also the results produced by the mono- and the stereoplotter can be used as input for the rectification software.

3. Geometric Models for Image Rectification

In many cases, a very simple model for image rectification will lead to satisfactory results :

$$Xi = a0 + a1*Xr + a2*Yr + a3*XrYr + a4*Xr*Xr + a5*Yr*Yr + ...$$
$$Yi = b0 + b1*Xr + b2*Yr + b3*XrYr + b4*Xr*Xr + b5*Yr*Yr + ... \qquad (1)$$

Xi, Yi = coordinates of the input image
Xr, Yr = coordinates of the rectified image
a0 ..., b0 ... = polynomial coefficients

Polynomial rectification can be applied if the imaging geometry of the sensor is not known or if the surface of the imaged object is approximately a plane.

If the image is a digitized photograph with central perspective geometry, the collinearity equations can be used for rectification :

$$\begin{bmatrix} Xp \\ Yp \\ -f \end{bmatrix} = \frac{1}{\lambda} \cdot R \cdot \begin{bmatrix} Xg - Xo \\ Yg - Yo \\ Zg - Zo \end{bmatrix} \qquad (2)$$

Xp,Yp = photo coordinates
f = focal length of the camera
λ = scale factor
R = rotation matrix of the orientation angles ω, φ, $\varkappa$
Xg,Yg,Zg = object space coordinates (ground coordinates)
Xo,Yo,Zo = ground coordinates of the projection center

For conversion of photo coordinates into image coordinates (Xi, Yi) an affine transformation is used :

$$Xi = a0 + a1*Xp + a2*Yp$$
$$Yi = b0 + b1*Xp + b2*Yp \qquad (3)$$

Small deviations from the central perspective geometry (e.g. the lens distortion) can be compensated by suitable correction models. Use of eq. 2 requires information about the surface of the imaged object (e.g. in form of a DTM).

In the case of line scanners, one or more CCD sensors are mounted in the focal plane of the optics. If all elements of the sensor are simultaneously read out at fixed intervals, the image of each line has also a central perspective geometry. For each scan line the collinearity equations can be written as :

$$\begin{bmatrix} 0 \\ Yp \\ -f \end{bmatrix} = \frac{1}{\lambda} \cdot R \cdot \begin{bmatrix} Xg - Xo \\ Yg - Yo \\ Zg - Zo \end{bmatrix} \qquad (4)$$

While the platform moves, the image is generated line by line. The exterior orientation of each single line is also given by 6 parameters. However the parameters of neighbouring lines are highly correlated.

At the Institute for Photogrammetry and Engineering Surveys of the University of Hannover a geometric model for the evaluation of line scanner images has been developed / Konecny et al. 1986, Kruck & Lohmann 1986 / which avoids high correlations between the adjusted unknowns.

It is assumed that the sensor is moving without acceleration during the period of data acquisition and the flight path from A to E may be considered to be a straight line (fig. 2). In this case the center of projection moves linearily from A to E and can be computed by :
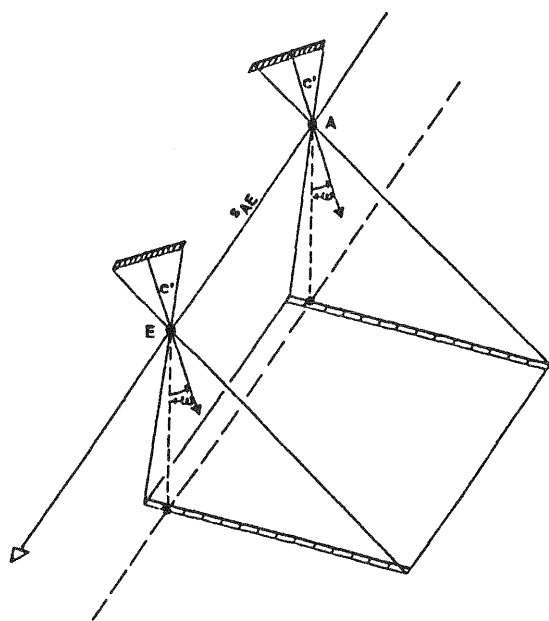
$$Xo,j = Xo,_A + j/n (Xo,_E - Xo,_A) \quad (5)$$

$$Xo = (Xo,j , Yo,j , Zo,j)$$

j = no. of the actual scan line

n = total no. of scan lines

Fig. 2 : Principle of CCD Line Scanner Imaging

The orientation angles $\omega, \varphi, \varkappa$ are regarded to be constant for all lines. This approximation represents the ideal case. In reality the model is disturbed by accelerations caused by maneuvering actions or the nonuniform gravity field of the earth and by the earth rotation. Because of the correlations of Xo with φ and Yo with ω the orbit can still be considered as straight whereas the orientation angles would be a function of time. The angular changes can e.g. be expressed as additional parameters.

In the Hannover bundle block adjustment program BINGO / Kruck 1987 / the described model has been realized. Distortions of the geometry are compensated by a set of 8 additional parameters. Approximate parameters for the flight path are computed from orbit data. Additional programs have been developed to use the results from BINGO for evaluation of SPOT images with analytical plotters / Konecny et al. 1987 /. Also programs for analytic (with Zeiss Orthocomp Z2) and digital rectification of SPOT images have been developed / Engel & Müller 1987 /. Meanwhile the described model has been realized within the rectification software of the ContextMAPPER system.

4. Rectification Programs

The most important steps in the process of image rectification are illustrated in fig. 3.

4.1 Image Orientation

The program IMORI (Image Orientation) can be used to determine the unknown orientation parameters of an image. This is done by least squares adjustment after measuring the image coordinates of control points. Depending on the selected geometric model these parameters are :

- the polynomial coefficients a0 ... and b0 ...,
- the parameters of the interior (a0, a1, a2, b0, b1, b2) and exterior orientation (Xo, Yo, Zo, ω, φ, $\varkappa$) in the case of central perspective images,
- the coordinates of the projection center (Xo, Yo, Zo), the direction of the flight path, the rotation angles and the additional parameters in the case of line scanner images (e.g. SPOT).
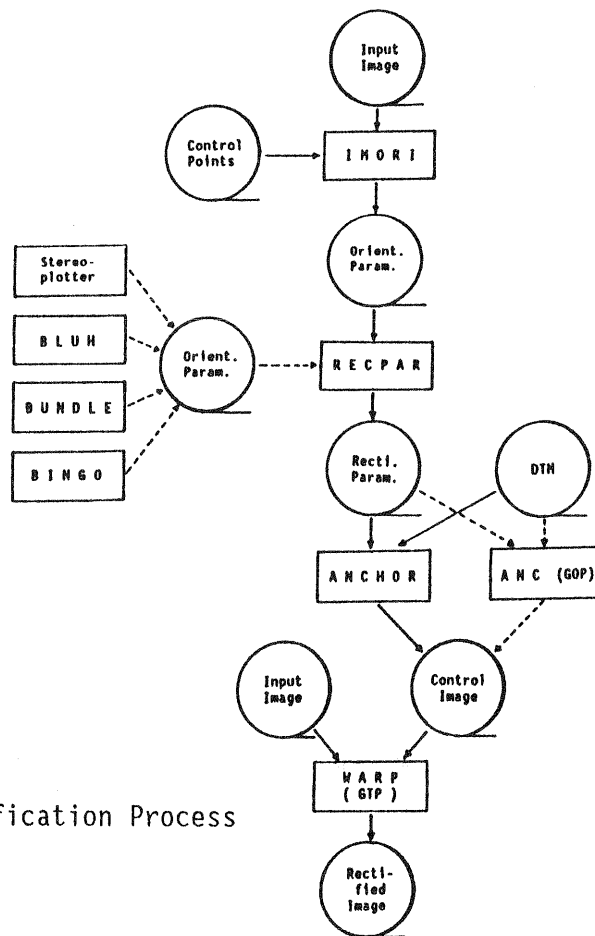
Fig. 3 : Rectification Process

The main features of the program are :

- Only a minimum number of control points must be identified in the down-
  sampled image. For precise measurement, sub-scenes with the control points
  in the middle are then displayed automatically in a predefined enlarged
  scale.
- Approximate values for the unknown parameters are determined by the program.
  In the case of central perspective images and line 1canner images the algo-
  rithm of / Hinsgen 1986 / is used.
- Optionally the control points are sorted in a sequence which gives an
  optimum distribution.
- After each new point measurement, the orientation parameters are updated
  and the residuals are displayed. Measurement of additional control points
  can then be stopped as soon as the result can not be further improved.

4.2 Rectification Parameters

For image rectification different types of parameters could be required :

- geometric model (depending on the sensor type),
- filename and size of the input image,
- orientation parameters,
- parameters for correction of systematic image errors,
- DTM parameters (e.g. filename, file type, format type, ground coordinates
  of the upper left corner, grid spacing, no. of grid points in x- and y-
  direction),
- parameters for transformation of DTM point coordinates into the coordinate
  system of exterior orientation.

The program RECPAR collects necessary rectification parameters and stores these parameters in a file which is used by the program ANCHOR. The following options can be used to make the collection of parameters easier :

- Extraction of parameters from existing files (e.g. output files of the bundle block adjustment programs BLUH and BINGO) is supported in order to save time and to avoid typing errors
- DTM parameters can be read from 'DTM description files'.
- The plausibility of input parameters is checked
- The printed parameter file can be used as a protocol sheet
- Parameters sets can be used to run the rectification as background or batch jobs

4.3 Rectification Method

In the ContextMAPPER system the 'indirect rectification' method has been realized in two steps. For a defined grid of points ('anchor points') within the rectified image, the corresponding image coordinates of the input image are computed by the program ANCHOR according to the selected geometric model (eq. 1 - eq. 5). In the case of central perspective images and line scanner images the anchor points are given by the DTM grid. The corresponding locations of output image pixels which lie between the anchor points are interpolated by the program WARP.

4.4 Generation of 'Control Images'

The program ANCHOR reads the DTM grid points (resp. generates a plane grid), transforms the ground coordinates into image coordinates and stores the image coordinates in a special format as a 'control image' for later use by the program WARP.

The main characteristics of the program are :

- DTM's of different file types (e.g. ASCII or DTM image) and data formats are accepted
- Different options for the correction of systematic image errors have been implemented (e.g. atmosheric refraction, lens distortion, additional parameters for the block adjustment programs BLUH and BINGO). As an alternative, systematic errors can be corrected by using 'correction grids'
- The influence of earth curvature can be compensated by 'earth curvature correction' of photo coordinates. If the photos are not near vertical, also a strict solution can be applied. In this case a local 3-dimensional cartesian coordinates system has to be used for exterior orientation. The program ANCHOR then transforms the DTM point coordinates from the national map projection system into the local system before entering into the collinearity equations

The program ANC in principle does the same as ANCHOR, but it uses the floating point processor of the GOP instead of the host processor. Since the floating point processor has no double precision data type, the accuracy is limited. The maximum error is in the range of 2 pixels. However for many applications this loss of accuracy can be accepted (e.g. if it is less than mapping accuracy or if the errors caused by the DTM are larger).

4.5 Resampling

The resampling is mainly done by the Geometric Transform Processor (GTP), described in section 5. This processor is programmed in a special macro language well suited for vector operations, and produces efficient micro code. The GTP has direct access to the system image memory where the input, control and output image will be located.

Frequently, the image to be resampled is too big to fit into the system image memory. In this case the image will be divided into smaller parts where each part in turn will be resampled and assembled into the final output image on disc. The subdivision is performed by the program "gtprun" which runs in the host and acts as an interface between the user and the GTP macro program. Thus, it performs the following tasks :

- loads down the target macro program into the GTP, if not already there,
- passes parameters typed in from the terminal or from files to the GTP program,
- splits the images in order to fit into the system image memory.

The WARP program interpolates the control image so that each pixel in the output image has a corresponding coordinate in the input image. This interpolation is done by the floating point part of the GTP. The integer part of the GTP interpolates in the input image. These interpolations are done in parallel.

4.6 Postprocessing Programs

If the rectified image shall be printed as an image map later on, some of the following post processing steps can be performed :

- radiometric enhancement to get optimized densities for output on film,
- radiometric matching of adjacent images,
- generation of contour lines from the DTM,
- generation of a map frame,
- insertion of cartographic supplements (e.g. place names, symbols).

If the rectified image is later used in a GIS , it could be necessary to change the map projection system (e.g. from Lambert to UTM) in order to combine the image with other data. According to the image size and scale and the required accuracy one of the following methods can be used :
- transformation of all pixels by polynoms or perspective projection,
- computation of anchor points and resampling.
Both methods are using the GTP.

5. Hardware Components

The GTP consists of two processors connected by a fifo, both running at 10 MHz. The GTP is an option to the ContextVision GOP 302.

The first processor is connected to the VME bus and has direct access to the image memory. This processors performes the interpolations using a fixed number of filters, one for each interpixel position. Only integer operations are performed here.

The second processor is mainly intended for coordinate computations, in which floationg point operations are computed at 10 MFLOPS.

6. Examples

In a practical test geocoded images for the area of the topographic map 1 : 25 000 Stadthagen have been produced. Images of the following sensors were used :

    a) colour infrared high altitude aerial photograph (HAAP)
    b) KFA 1000 space photograph
    c) LANDSAT TM
    d) SPOT (multispectral)

An Optronics P1700 drum scanner was used to convert the analog HAAP and KFA photograph into digital images. Since a resolution of 25 microns was selected, only the part with the test area was scanned in order to reduce the amount of data. The size and ground resolution of the input images and geocoded images are listed in table 1.

	HAAP	KFA 1000	LANDSAT TM	SPOT
date of exposure	3-6-1982	6-8-1986	25-4-1984	18-5-1986
focal length [mm]	85.52	1013.47	-----	(2087.40)
flying height [km]	11.6	275.7	705	830
input image : size (rows,cols)	4000x4000	2800x2800	5661x7020	3000x3000
ground resolution [m]	(3.4)	(6.8)	30.0	20.0
output image : size (rows,cols)	2280x2320	1140x1160	570x580	570x580
ground resolution [m]	5.0	10.0	20.0	20.0

Table 1 : Description of Image Data

Digitized contour lines were used to interpolate a DTM with a grid spacing of 100 m. The maximum height difference was 159 m.

The orientation parameters of the HAPP image were determined by the program IMORI with 9 control points from 1 : 5000 base maps. Photo coordinates of the control points (measured with Planicomp 100) were used to compute the coefficients for transformation of photo- into image coordinates ('interior orientation', eq. 3).

For a short strip of 3 KFA 1000 photographs, photo coordinates were measured with the Planicomp C100 analytical plotter and a bundle block adjustment was computed using the block adjustment program BLUH / Jacobsen & Müller 1988 /. The parameters of 'exterior orientation' (X_o, Y_o, Z_o, ω, φ, $\varkappa$, eq. 2) of the digital image were then extracted from a file with the results of BLUH. The parameters of interior orientation were determined in the same way as for the HAPP image. A correction grid was used to compensate systematic image errors.

Image coordinates of 27 control points from maps 1 : 25 000 were measured in the LANDSAT TM image. The control points were regularly distributed over the whole scene. Polynom coefficients (eq.1) of a polynom of 2nd degree were then computed by least squares adjustment.

For the SPOT image, the parameters of exterior orientation and the additional parameters were computed with the bundle block adjustment program BINGO / Engel & Müller 1987 /. Therefore the required rectification parameters could be read from the BINGO output file.

Table 2 gives an overview of the obtained internal accuracy. The elapsed time of the programs ANCHOR (resp. ANC) and WARP is listed in table 3. The absolute geometric accuracy of the rectified images was controlled by measurement of independent check points in the geocoded digital images. The 'true' Gauß-Krüger coordinates of the check points were taken from maps 1 : 5 000 and 1 : 25 000. The results are listed in table 4.

Image	Control Points	X [m,(pix)]	Y [m,(pix)]
HAPP	9	4.1 (1.2)	3.8 (1.1)
KFA 1000	8	9.2 (1.4)	7.1 (1.0)
LANDSAT TM	27	12.3 (0.4)	12.5 (0.4)
SPOT	16	4.1 (0.2)	2.2 (0.1)

Table 2 : Root Mean Square of Residuals at Control Points

Image	ANCHOR	ANC	WARP
HAPP	184	24	220
KFA 1000	189	24	51
LANDSAT TM	175	--	15
SPOT	245	--	11

Table 3 : Elapsed Time (CPU + IO) in Seconds

Image	No. of Check Points from Maps 1 : 5000	1 : 25000	X [m,(pix)]	Y [m,(pix)]
HAPP	13	--	6.9 (1.4)	6.7 (1.3)
HAPP	--	41	7.4 (1.5)	7.5 (1.5)
HAPP (ANC)	13	--	11.5 (2.3)	11.5 (2.3)
HAPP (ANC)	--	41	11.5 (2.3)	11.6 (2.3)
KFA 1000	11	--	12.7 (1.3)	12.4 (1.2)
KFA 1000	--	32	13.4 (1.3)	13.2 (1.3)
KFA (ANC)	11	--	24.4 (2.4)	24.3 (2.4)
KFA (ANC)	--	32	24.5 (2.5)	24.4 (2.4)
LANDSAT	--	12	30.2 (1.5)	31.8 (1.6)
SPOT	11	--	24.4 (1.2)	22.9 (1.1)
SPOT	--	29	25.7 (1.3)	23.2 (1.2)

Table 4 : Root Mean Square of Differences at Independent Check Points

7. Future Developments

With the existing software images of the most used sensors (cameras, LANDSAT, SPOT) can be rectified. In the next step, the software will be extended to handle also panoramic images. A solution for the geometry of panoramic images is already available within the bundle block adjustment program BLUH / Jacobsen 1988 /.

For architectural applications a new program package will be developed which enables rectification of photos from objects whose surface can be described mathematically (e.g. as cylinder, sphere, triaxial ellipsoid etc.) This rectification method can e.g. be used for documentation of historic towers or domes / Vozikis 1983 /.

Because of the growing importance, also a program package for rectification of radar images is planned. The method will be based on correlation of the original image with a simulated image generated from a DTM.

Normally the control points used for image rectification are taken from existing large scale maps. Since map coverage is not always complete, investigations are under way to reduce the number of necessary control points by using orbit data.

References

Engel, H., Müller, W. : Orthocomp Operation of SPOT Imagery
Seminar on Photogrammetric Mapping from SPOT Imagery, Hannover, 1987

Hinsgen, J. : Algorithmen zur Beschaffung von Näherungswerten für die
Orientierung von beliegig im Raum angeordneten Strahlenbündeln
Dissertation, DGK Reihe C, München 1987

Jacobsen, K. : Handling of Panoramic and Extreme High Oblique Photographs
in Analytical Plotters
Proc. ISPRS Congress, Kyoto 1988

Jacobsen, K., Müller W. : Geometric Potential of Space Images
Proc. ISPRS Congress, Kyoto 1988

Konecny, G. : Metric Problems in Remote Sensing
Proc. ISP Com. IV Symp., ITC Delft, 1971

Konecny, G., Kruck, E., Lohmann, P. : Ein universeller Ansatz für die
geometrische Auswertung von CCD-Zeilenabtasteraufnahmen
BuL 54 (1986), Vol. 4, pp. 139 - 146

Konecny, G., Lohmann, P., Engel, H., Kruck, E. : Evaluation of SPOT Imagery
on Analytical Photogrammetric Instruments
Photogrammetric Engeneering

Kruck, E., Lohmann, P. : Aerial Triangulation of CCD Line-Scanner Images
Proc. ISPRS Com. I Symp., Stuttgart, 1986

Kruck, E. : Bundle Block Adjustment Program BINGO for SPOT Imagery
Seminar on Photogrammetric Mapping from SPOT Imagery, Hannover, 1987

Lohmann, P., Weidenhammer, J., Picht, G., Jacobsen, K., Skog, L. :
The Design and Implementation of a Digital Stereo Workstation
Proc. ISPRS Congress, Kyoto 1988

Vozikis, E. : Digitally Controlled Differential Rectification of Mathematically
Defined Surfaces
Photogrammetria, Vol. 38 (1983) pp. 165 - 180