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METHODS, ACCURACY REQUIREMENTS AND APPLICATIONS OF DIGITAL IMAGE RECTIFICATIONS

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1. Introduction

Due to the advantage of simultaneous digital radiometric and spectral imagery acquisition, and complete digital processing possibilities, digital sensors have become growingly important as a valuable complement to conventional photographic imagery. This holds specially true for the new generation of high-resolution CCD-sensors. Their high geometric accuracy and fidelity necessitates the incorporation of a digital elevation model (DTM) in the geometric image processing steps in order to fully make use of the input image quality to obtain high quality output image products (Ortho-imagery). This in turn requires a stronger interaction between the image processing techniques and the photogrammetric orthophoto techniques of recent years.

2. Imaging geometry

In the following the analogies between conventional photographic cameras and corresponding remote sensing sensors will be shown (see Fig. 1), where these definitions below will be used:

c = focallength of camera/Sensor
x,y = image space coordinates
X,Y,Z = object space coordinates
X_o,Y_o,Z_o = object space coordinates of the center of projection
D = matrix of orientation angles ω,ϕ,κ
λ = scale factor
θ_j = y_j/c, scanning angle

subscript j = denoting functional dependency of the time of acquisition t_j

The well-known collinearity equations

$$\begin{bmatrix} x \\ y \\ -c \end{bmatrix} = \frac{1}{\lambda} D \begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix} \qquad (1)$$

describe the imaging geometry of the conventional aerial camera (see Fig. 1a). The strip camera (see Fig. 1b) images the object space stripwise in a central-perspective manner, the orientation elements and the x-image coordinates being a function of the time of acquisition t_j. This imaging process can be described by the equations (2):

$$\begin{bmatrix} 0 \\ y \\ -c \end{bmatrix} = \frac{1}{\lambda_j} D_j \begin{bmatrix} X - X_{oj} \\ Y - Y_{oj} \\ Z - Z_{oj} \end{bmatrix} \qquad (2)$$

The imaging geometry of the panoramic camera (see Fig. 1c) requires incorporation of the rotation matrix R_j whose elements are functions of the scanning angle θ_j:

$$\begin{bmatrix} x \\ 0 \\ -c \end{bmatrix} = \frac{1}{\lambda_j} R_j D_j \begin{bmatrix} X - X_{oj} \\ Y - Y_{oj} \\ Z - Z_{oj} \end{bmatrix} \quad \text{with } R_j = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_j & \sin\theta_j \\ 0 & -\sin\theta_j & \cos\theta_j \end{bmatrix}$$

By simple matrix manipulations one obtains the equivalent relation

$$\begin{bmatrix} x \\ -c \sin\theta_j \\ c \cos\theta_j \end{bmatrix} = \frac{1}{\lambda_j} D_j \begin{bmatrix} X - X_{oj} \\ Y - Y_{oj} \\ Z - Z_{oj} \end{bmatrix} \qquad (3)$$

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For the Optical-mechanical scanner (see Fig. 1d) the collinearity equations (4) describe the imaging process at every instant t_j in a local coordinate system:

$$\begin{bmatrix} 0 \\ 0 \\ -c \end{bmatrix} = \frac{1}{\lambda_j} R_j D_j \begin{bmatrix} X - X_{oj} \\ Y - Y_{oj} \\ Z - Z_{oj} \end{bmatrix} \qquad (4)$$

The image coordinates x,y become functions of t_j and θ_j. By matrix operations one can rearrange equation (4) into the equivalent form

$$\begin{bmatrix} 0 \\ -c \sin\theta_j \\ c \cos\theta_j \end{bmatrix} = \frac{1}{\lambda_j} D_j \begin{bmatrix} X - X_{oj} \\ Y - Y_{oj} \\ Z - Z_{oj} \end{bmatrix} \qquad (5)$$

The Optical-electronic scanner (CCD-Sensor) of Fig. 1e) has identical imaging conditions as the strip camera, and Matrix camera of Fig. 1f) has imaging characteristics described by the well-known collinearity equations (1).

In order to readily compare the different imaging geometries, Table 1 shows the left hand sides of all imaging equations, which (except for subscriptj) possess identical right hand sides.

From table 1 follows that

- the imaging principle of each remote sensing sensor has its equivalent in a (more or less modified) photographic camera system,
- data processing of sensor imagery can be implemented using modified photogrammetric techniques,
- the optical-electronical scanner offers tremendous advantages with respect to imaging quality in comparison to the optical-mechanical scanner.

3. Methods for rectification

The implementation of digital image rectifications requires the derivation of an analytical relationship between image space coordinates x,y and object space coordinates X,Y,Z.

Nonparametric methods are of the general form

$$x = f(X,Y) \; ; \; y = g(X,Y) \qquad (6)$$

and have the following properties:

- summaric modelling of all distortions
- pure two-dimensional interpolations and/or predictions
- non-applicability of digital elevation models
- non-applicability of specific sensor imaging characteristics.

Parametric methods, however, model the sensor imaging process explicitly and are of the general form (see Fig. 2)

$$\begin{aligned} x &= f(\omega,\phi,\kappa,X_0,Y_0,Z_0,c,X,Y,Z) \\ y &= g(\omega,\phi,\kappa,X_0,Y_0,Z_0,c,X,Y,Z) \end{aligned} \qquad (7)$$

with deterministic (e.g. Mikhail 1975) and/or stochastic (e.g. Ebner 1976) models

$$\begin{aligned} \omega &= \omega(x) \\ &\vdots \\ Z_0 &= Z_0(x) \end{aligned} \qquad (8)$$

for the time- and therefore also scan line-dependent sensor orientation elements. The consideration of a digital elevation model and consequently image rectifications with pixel-accuracy for any type high-resolution sensor herewith becomes possible.
Table 2 displays the elevation accuracy required to yield pixel-accuracy for various satellite sensor systems.

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The actual rectification process, i.e. the quantization of the output image using the input imagery pixels, is carried out typically as follows (see Fig. 3): First regular "anchor point" locations are defined in the output image coordinate system X,Y. Then, the corresponding point locations in the input image are computed using a set of equations such as (6) or (7). The spacing of the regular anchor point set is chosen such that bilinear interpolation inside a set of four anchor points can be used without loss of accuracy. Typical spacings might be 10-20 pixels, depending on the image resolution, the terrain relief present and the control point spacing and accuracy. Once this anchor point set has been derived, the quantization is carried out by defining a X,Y position, computing the corresponding x,y position in the input image, and assigning to this generally noninteger x,y position an interpolated gray-value which is finally used to fill the output image matrix at position X,Y.
This process is repeated for all X,Y positions until the output image has been quantized.

4. Accuracy requirements

A positional accuracy of half a pixel size represents for the time being a reasonable, manageable accuracy requirement for ortho imagery. This in turn requires that the control points to be used during the geometric processing stages must be defined with an accuracy better than half a pixelsize. Recently investigated correlation techniques (Förstner, 1982), capable of defining point locations within a RMSE of a few tenth of a pixelsize, form a valuable complement to existing automated and visual point transfer techniques.

According to table 2, the geometric processing of satellite imagery from SPOT and THEMATIC MAPPER will require the use of a digital elevation model of about ± 100 meters accuracy in order to obtain pixel-accurate rectification results. For the Federal Republic of Germany this means that for example all contour lines of the IMW 1:1.000.000 must be available in digital form.

For the digital rectification of aircraft scanner imagery as well as digitized aerial photography hold the same accuracy requirements as one is familiar from analog orthophoto production. Figure 4 shows a comparison of the analog and the digital orthophoto approach. One recognizes that there exists a very high correspondence in the processing stages, the anchor points of Figure 3 being represented in Figure 4 by the line intersections.

Besides an adequate geometric positional accuracy it is important to require a high fidelity of the radiometric image quality, i.e. a high-quality output image. During the quantization of the output image a resampling technique must be therefore applied which conserves as high a frequency content of the input image as possible. This can be accomplished only by using higher order pixel interpolation (assignment) methods such as e.g. the cubic convolution.

Mosaicking of several imageries further requires a digital radiometric adjustment at the mosaic-patch boundaries (e.g. Göpfert, 1981). This can be accomplished by incorporating local and/or global correction functions for contrast and average image gray-values, whose coefficients are computed using overlapping mosaic-patches.

Finally it should be pointed out that the superposition of grid lines into rectified imagery, which can be performed by a rather trivial procedure, is very often a meaningful last processing step in digital geometric processing and saves manual absolute orientation works.

5. Applications

The application spectrum of digital image rectifications is very large and includes e.g.

- production of ortho imagery and ortho image mosaics of any arbitrary remote sensing imagery,
- digital orthophoto production using digitized aerial photography, and
- generation of thematic data bases from digitized cartographic folies and/or any arbitrary transparency with the option of geometric transformation from one map projection into another projection.

These rectified imagery and/or thematic data can be further processed using automated thematic processing such as image segmentation, classification and pattern recognition techniques. By combined processing of multisensor and cartographic data a large variety of areas such as planning, information processing and land information systems can be readily supported in solving their application-oriented tasks.

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6. Literature

Ebner, H., 1976. A Mathematical Model for Digital Rectification of Remote Sensing Data. Presented Paper, Commission III, ISP, Helsinki, 1976.

Förstner, W., 1982. On the Geometric Precision of Digital Correlation. Proc. of the Comm. III Symposium, Helsinki, 1982, S. 176-189.

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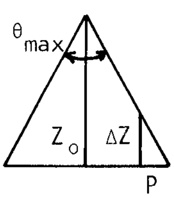
Kraus, K., 1982. Geländehöhendatenbank und Bildflugdatei im Dienste der Fernerkundung. Vortrag anläßlich der wissenschaftlich-technischen Jahrestagung der DGPF am 19./20.11.1981 in München (veröffentlicht in der Neujahrsausgabe Januar 1982 der DGPF, S. 1-13).

Mikhail, E.M. and McGlone, J.C., 1981. Photogrammetric Analysis of Aircraft MSS data. Purdue University Publication CE-PH-81-3, 1981.

Photographic cameras		Remote sensing sensors	
Aerial camera: (Fig. 1a)	$\begin{bmatrix} x \\ y \\ -c \end{bmatrix}$	Matrix camera: (Fig. 1f)	$\begin{bmatrix} x \\ y \\ -c \end{bmatrix}$
Strip camera: (Fig. 1b)	$\begin{bmatrix} 0 \\ y \\ -c \end{bmatrix}$	Optical-electronical Scanner: (Fig. 1e)	$\begin{bmatrix} 0 \\ y \\ -c \end{bmatrix}$
Panoramic camera: (Fig. 1c)	$\begin{bmatrix} x \\ -c \sin\theta_j \\ c \cos\theta_j \end{bmatrix}$	Optical-mechanical scanner: (Fig. 1d)	$\begin{bmatrix} 0 \\ -c \sin\theta_j \\ c \cos\theta_j \end{bmatrix}$

Table 1: Comparison of the imaging equations



Sensor	Z_o (km)	θ_{max}	P(m)	ΔZ(m)
MSS Landsat 1-3	920	$11{,}5^0$	80	780
Thematic Mapper	705	15^0	30	230
Spot (1984)	822	$4{,}3^0$	10	266

Table 2: Pixelsize P and corresponding difference in elevation ΔZ at the image edges (Kraus, 1981)

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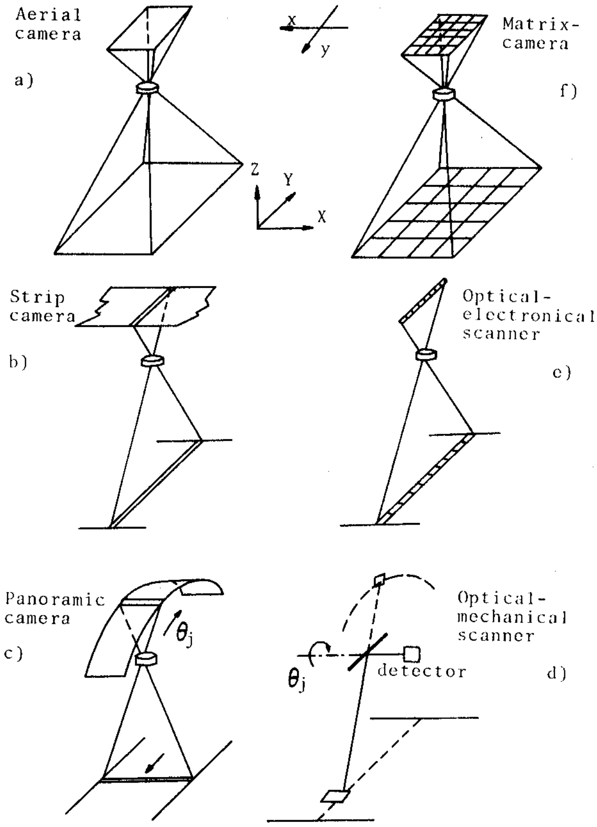

Fig. 1:
Geometries of data acquisition systems
Left column: photographic systems
Right column: remote sensing passive sensors

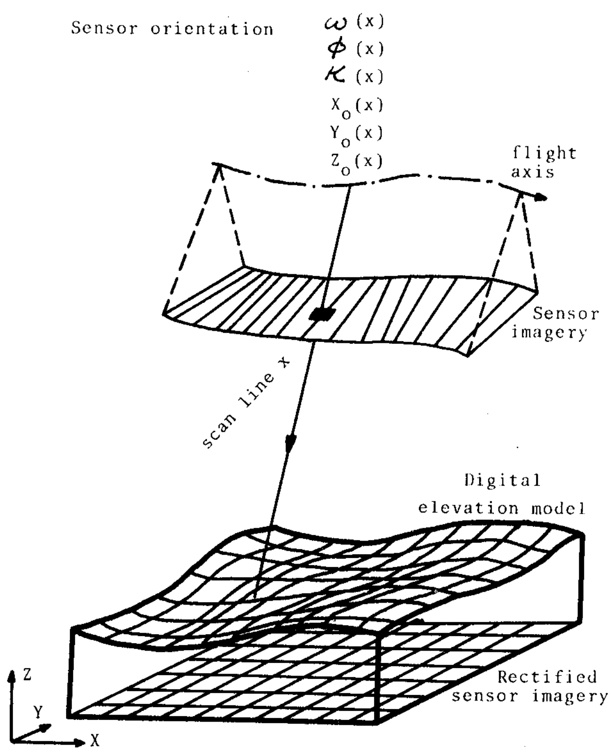

Fig. 2:
Principle of scanner imagery acquisition and rectification

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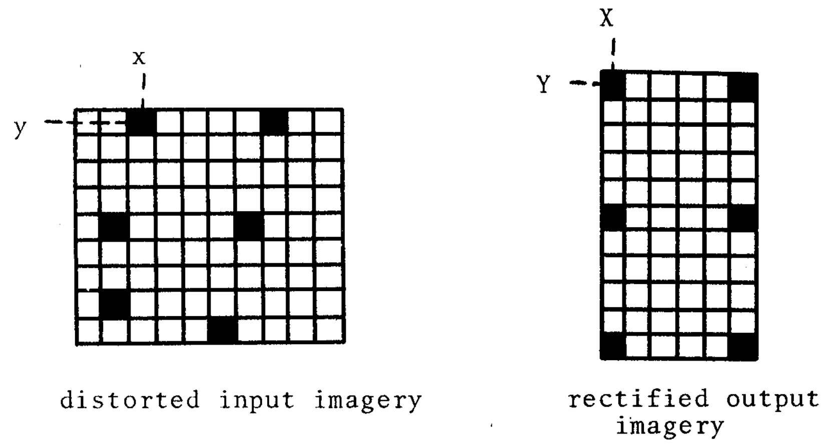

Fig. 3: Principle of the rectification (requantization) procedure. Black squares represent anchor point locations in the imageries.

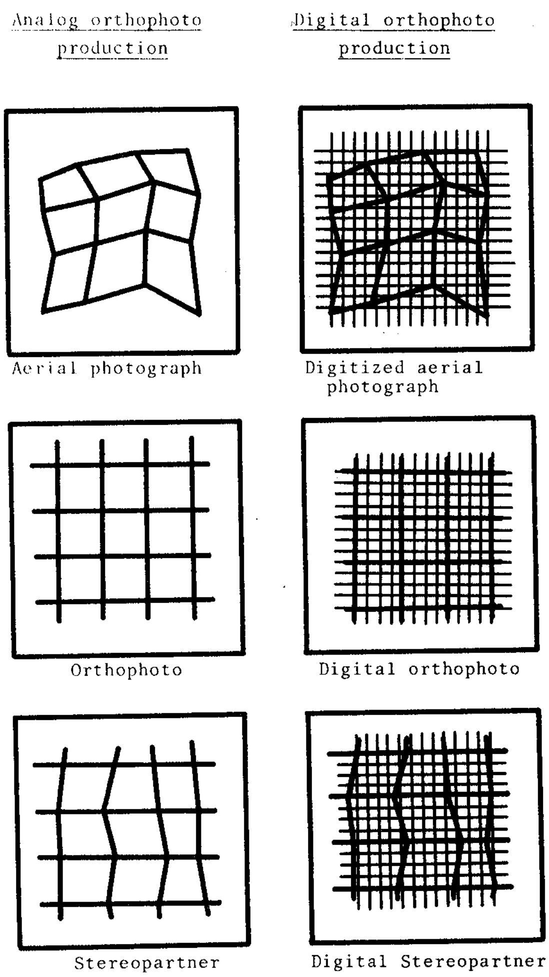

Fig. 4:
Comparison of analog and digital orthophoto production
Heavy lines denote corresponding distorted and rectified locations.

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SUMMARY

The new generation of high-resolution aircraft and satellite scanning systems requires consideration of a digital elevation model during the various geometric processing steps. This will result in stronger interactions with the methods of conventional photogrammetry, for example with recent orthophoto techniques. Accuracy requirements as well as potential applications of digital image rectifications will be discussed.

ZUSAMMENFASSUNG
METHODEN, GENAUIGKEITSANFORDERUNGEN UND ANWENDUNGSMÖGLICHKEITEN DIGITALER BILDENTZERRUNGEN

Die neue Generation hochauflösender Flugzeug- und Satelliten-Abtastsysteme erfordert die Einbeziehung eines digitalen Geländemodells in die geometrischen Verarbeitungsverfahren. Daraus resultiert eine noch stärkere Einbindung in die Verfahren der konventionellen Photogrammetrie, insbesondere in die neuere Orthophototechnik. Auftretende Genauigkeitsanforderungen und Anwendungsmöglichkeiten digitaler Bildentzerrungen werden diskutiert und aufgezeigt.

RESUME
METHODES, EXIGENCES DE PRECISION ET POSSIBILITES D'APPLICATION DU REDRESSEMENT NUMERIQUE D'IMAGES

La nouvelle génération des systèmes de balayage de haute résolution utilisés dans les avions et les satellites exige l'intégration d'un modèle altimétrique digitalisé dans les procédés de traitement géométrique des informations. Il en résulte une interaction encore plus forte avec les procédés photogrammétriques conventionnels, en particulier avec les techniques récentes appliquées pour la confection d'orthophotos. L'exposé pose le problème de la précision exigée et des possibilités du redressement numérique des image.

RESUMEN
METODOS, EXIGENCIAS DE PRECISION Y POSIBILIDADES DE APLICACION DE RECTIFICACIONES DIGITALES DE IMAGENES

La nueva generación de sistemas de exploración con resolución elevada en aviones y satélites requiere la inclusión de un modelo digital de elevación en los varios procesos geométricos de tratamiento resultando en interacciones más fuertes con los métodos de la fotogrametría convencional, particularmente con técnicas recientes para la confección de ortofotos. Se discuten exigencias de precisión y posibilidades de aplicación para rectificaciones digitales de imágenes.

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