AN APPLICATION OF ATTITUDE AND TERRESTRIAL DATA TO GEOMETRIC CORRECTION OF AERIAL SCANNER IMAGERY

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1. Introduction

Aerial scanner images in terms of geometry, resolution, and fidelity depart radically from their photographic counterparts. Geometric distortions of the scanner images are caused mainly by combination of the dynamic image generation with the variation of the exterior sensor orientation during the flight time. They are rather complicated because the dynamic distortions superimpose to the deformations introduced by the errors of interior orientation elements of the sensor.

The correction of these image deformations requires either representation of data orientation parameters or a dense set of ground control points. However, the time dependent orientation data measured by aircraft instruments are till now directly known with adequate accuracy. From the other hand, the identification of a large number of ground control points appears a time-consuming procedure. Since 1970's various methods of scanner image correction have been developed [Konecny 1971, 1972, 1975, 1976], [Baker et.al.1975], [Ebner 1976], [Kraus 1976], [Gopfert 1981], [Weisel 1981] and [Schur 1983]. The method presented in the paper uses both attitude data (parameters measured during the flight) and terrestrial data (ground control points), and can be applied to correction of single scanner images taken from an aircraft. Digital terrain model (DTM) is necessary when relief of the terrain contributes to radial distortion higher than a pixel size.

2. The method of correction

The input data are scanner digital data stored on CCT (which contain also video data and flight parameters) and coordinates of ground control points as well as DTM terrain information, which can be gathered from large scale maps.

The exterior orientation data are denoted as:

$$\left\{ Q_i \right\} = \left\{ X_{oi},\ Y_{oi},\ Z_{oi},\ \omega_i,\ \phi_i,\ \varkappa_i \right\}$$

where: $i = 1,\dots,I$ - number of pixel line

X_{oi}, Y_{oi}, Z_{oi} - ground coordinates of instantaneous projection centre for pixel line i (at the beginnig known only in flight local coordinate system and therefore, later transformation to ground coordinate system is required),

ω_i, ϕ_i, $\varkappa_i$ angles of instantaneous scanner orientation for pixel line i.

The coordinates of ground control points X_n, Y_n, Z_n and image coordinates i_n, j_n are expressed as:

$$\left\{ R_n \right\} = \left\{ X_n,\ Y_n,\ Z_n,\ i_n,\ j_n \right\}$$

where: $n = 1, \ldots, N \geq 11$ - number of ground control points, i - line number, j - pixel possition in the line (image visualization is required for determination of these coordinates).

The set of coordinates X_m, Y_m, Z_m (D T M) of freely distributed points (which inform about terrain relief) is denoted as:

$$\left\{ T_m \right\} = \left\{ X_m,\ Y_m,\ Z_m \right\}$$

where: $m = 1, \ldots, M$ - number of D T M points.

The terrain relief information $\{ T_m \}$ given by interpolation using two dimensional third order splines [Zavijalow 1980].

2.1. Correction functions

For the images to be corrected two empirically established functions are used [Pyka 1985]:

a) basic

$$dX' = f_x(X',Y') = A_0 + A_1X' + A_2Y' + A_3X'^2 + A_4X'Y' + A_5Y'^2 + A_6X'^3 + A_7X'^2Y' + A_8X'^2Y'^2 + A_9X'^4 + \ldots \tag{1a}$$

$$dY' = f_y(X',Y') = B_0 + B_1X' + B_2Y' + B_3X'^2 + B_4X'Y' + B_5Y'^2 + B_6X'^3 + B_7X'^2Y' + B_8Y'^3 + B_9X'^2Y'^2 + B_{10}X'^3Y'^2 + B_{11}X'^4Y'^3 + \ldots \tag{1b}$$

where: dX', dY' - corrections changing pixel possition (on the reference plane shown in Fig.1) to correct place (point R"), X', Y' - ground coordinates calculated according to the collinearity equations for scanner imagery [Konecny, 1971], using exterior orientation data ,$\{Q\}$ and image pixel $r(i,j)$ coordinates i and j of control points.

b) auxiliary

$$i = F_x(X,Y) = C_0 - C_1X - C_2Y - C_3X^2Y - C_4XY - C_5Y^2 - C_6X^3 - C_7X^3Y \ldots \tag{2a}$$

$$j = F_y(X,Y) = D_0 - D_1X - D_2Y - D_3X^2 - D_4XY - D_5Y^2 - D_6X^3 - D_7X^3Y - D_8XY^3 - D_9X^2Y^2 \ldots \tag{2b}$$

X,Y-ground coordinates of control points determined in set $\{R_n\}$

The coefficients A,B,C,D of basic and auxilliary correction functions are obtained by least square solution of equations (1) and (2) for N ground control points.

Registered during the flight attitude parameters (external orientation elements) are not errorfree and have systematic character [Schuhr and Konecny,1984]. Therefore, simple formulae (1) can be used satisfactorily for computation of correction vectors dX'dY'; and to eliminate the errors from the data $\{Q\}$.

As we don't know the character of the errors, we should also consider other errors sources of scanner images (electronic distortion, atmospheric refraction, effect of terrain relief). It is the reason why the special polynomials (*1*) were empiricaly determined with terms which ignore geometrical interpretation of particular coefficients.

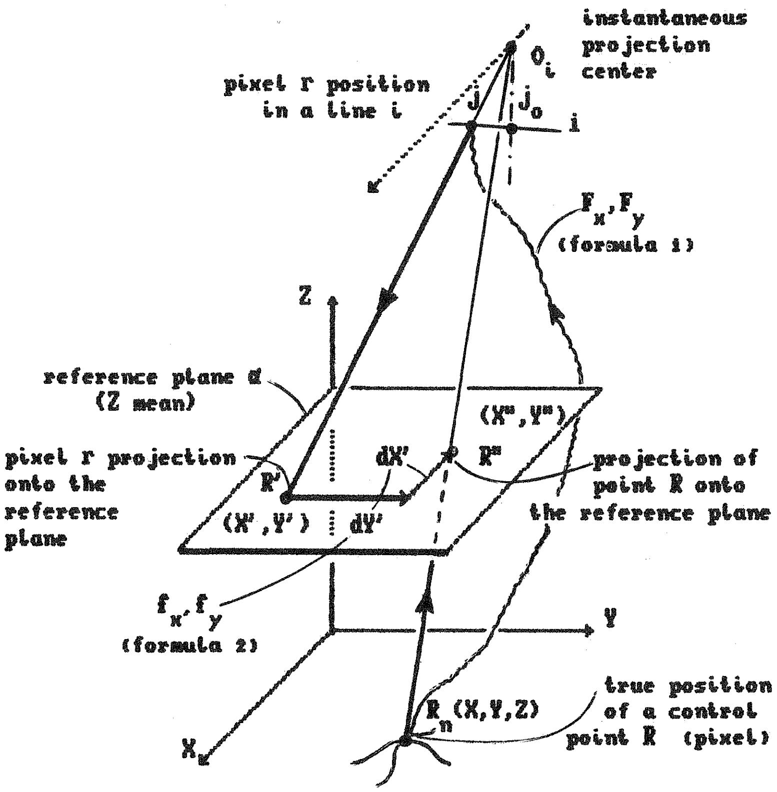

Fig.1 Schematic presentation of the correction procedure idea (R - control points)

For computation of unknown coefficients A_i.. and B_i ... of formulae (*1*), each ground control point is used for determination of:

- X',Y' coordinates using and collinearity equations and $\langle Q_i \rangle$ data (pixel r is projected to R'- Fig.1),
- X", Y" coordinates which can be found as the intersection of stright lines RO_i(Fig.1) and reference plane α (terrain pixel R is projected onto R"),
- coordinate differences dX' = X" - X' and dY' = Y" - Y'.

The horizontal reference plane α is passing through the mean hight of the terrain. The differences in terrain heights have to be taken into account during the correction process. It is done when $\langle T_m \rangle$ DTM, exterior orientation data and collinearity equations are used for computation of ground coordinates X',Y'.

The auxiliary special polynomials (2) form the function not parametric type (have been found empirically), and express image coordinates (i,j) as function of ground coordinates (X,Y).

In case when mechanical scanner is used the image coordinates of left side in equation (2b) should be related to scan angle

$(j-j_o)$ - Fig.1. Therefore the auxiliary parameter k is introduced for computation of coordinates $j = c.k$

$$k = tg(j - j_o)\ IFOV_b \qquad (3)$$

where: j_o - position of central pixel in line i (Fig.1), $IFOV_b$ - *Instantenous Field of View* along line i.

2.2. Formation of corrected image (resampling)

For gray level adjustment and formation of corrected image, the indirect method is applied. It means that for a corrected image plane and for any terrain pixel (X,Y,Z) - the position of corresponding original image pixel is to be found [Konecny and Schuhr, 1975].

The process consists of the following calculations ilustrated also partly on Fig.2:

I - For image pixel (i,j) of point p (i,j) the ground coordinates X,Y are established. DTM are used to developed the height Z of point P(X,Y) - Fig.2.

II - For calculation of pixel p image coordinates (i,j) the formulae (2), and established in step I corresponding ground coordinates (X,Y) are used. The formulae (2) compensates only a part of geometric deformations and aproximation are worse when differences interrain heights increase.

III - The terrain pixel P(X,Y,Z) is projected onto the reference plane α from the projection center point O_i - as a result of intersection with a reference plane, the coordinates X",Y" are obtained (point = pixel P is transfered to point P").

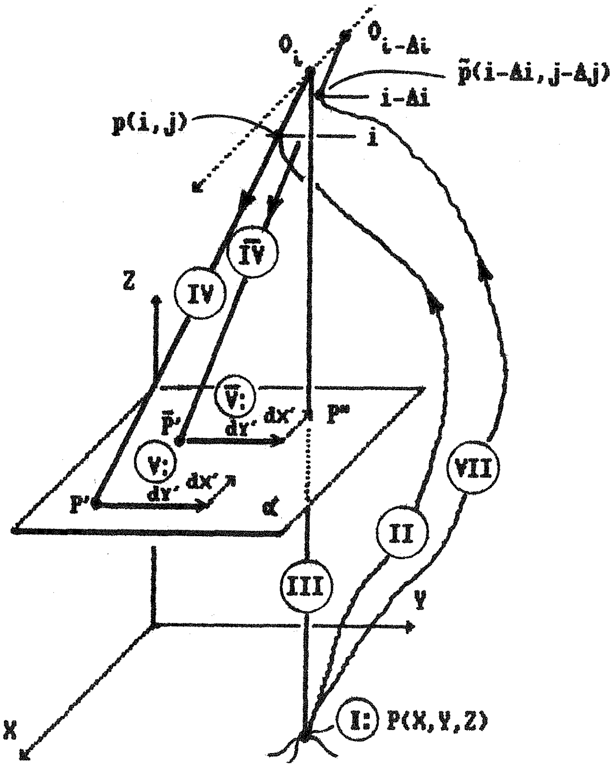

Fig.2. Illustration of steps in formation of corrected corrected scanner image (P - reference pixel see Fig.3)

IV - Using orientation data and collinearity equations the image pixel $p(i,j)$ is also projected in the same way onto plane α, but to pixel $P'(X',Y')$.

V - The correction vectors dX', dY' obtained from the formulae (*1*) are assigned to each pixel $P'(X',Y')$ and then, the following conditions are examined:

$$X' + dX' = X'' \qquad (4)$$
$$Y' + dY' = Y''$$

For compatibility of above equations, the accuracy of correction procedure is assumed (eg. ± 1 PX where PX is pixel size of corrected imagery). If the conditions (*4*) are fulfilled, the procedure is moved to accomplish step VII. Usually, during the first iteration the conditions are not fulfilled and step VI is needed.

VI - The iterative procedure based on the concept given by [Schuhr, 1983] is applied to compute new image coordinates which replace the one calculated in step II. In this procedure the corrections $(\Delta i, \Delta j)$ are added to the initial coordinates (i,j). New image pixel $p[(i+\Delta i), (j+\Delta j)]$ is then projected onto the reference plane α using the same data and equations like in step IV, and new point $\tilde{P}'(\tilde{X}',\tilde{Y}')$ - Fig.2 is computed. Now calculations mentioned in steps I to V are repeated for this point, and conditions (*4*) are checked. If it is not fulfilled further - a decision should be taken either to change a signs or the values of new corrections. It is continued until the conditions (*4*) have been fulfilled.

VII - To computed pixel $P''(X'',Y'')$ - for which condition (*4*) is performed - the identification of the input pixel and the transfer of its gray shade constitutes the nearest neighbourhood assigment.

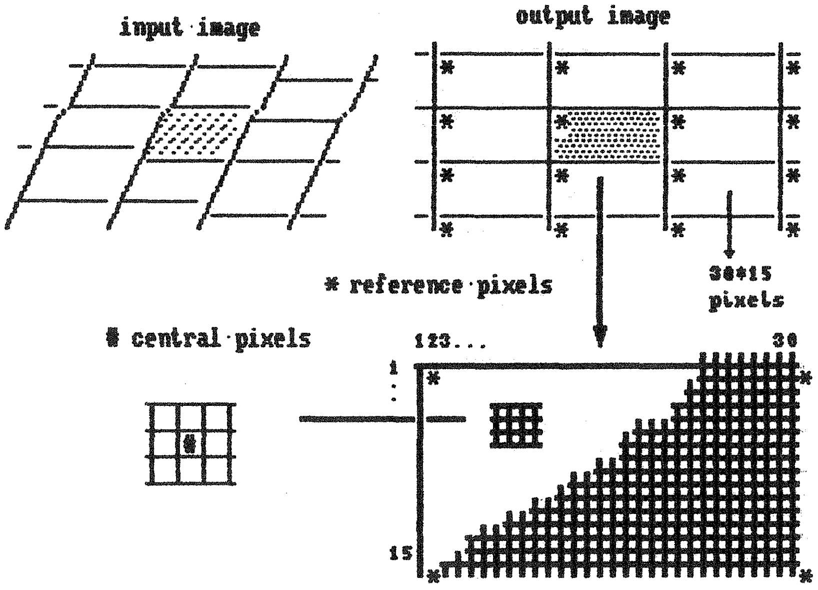

Fig.3 Resampling (right side - the output image of the mesh size 30x15 pixels with four reference pixels; left side - the input image overlay on output)

Thereby, a corrected (rectified) image can be formed succesively - pixel by pixel. In in view of numerical procedure it is a time consuming process. Therefore, it is applied to the reference pixels only (see Fig. 3). For pixels which are located within that reference mesh, the corrections can be calculated using simple interpolation (the bilinear interpolation was applied [Schuhr, 1983]. Only central pixel area sized by 3x3 pixels (see Fig. 3) were corrected in this way. For the remaining eight pixels, which surround the central pixel, the intensity values of gray shade are transfered directly from the eight neighbours of central image pixel (i, j).

3. Results of testing

The proposed method was applied to correction of two scanner images taken for two different testing areas. (Image A in FRG and Image in Poland). The technical data of the terrain and images are listed in table 1. The same [Schuhr, 1983] or similar [Rose, 1984] images taken by M^2S Bendix scanner, and [Babos, 1982] taken by C 500 scanner were corrected.

Table 1

Technical data of A and B images and field used for testing

Type of data	Image A "Freiburg"	Image B "Środa Śl."
1 Data	1976.05.14	1978.07.18
2 Scanner type/field of view	M^2S Bendix/100	C 500/28,6
3 Height of flight m Speed km/h	2300 240	6300 470
4 Variation of external orientation elements	high for the whole scene	high for the first 100 lin
5 Pixel size: - angular [mrd^2] $IFOV_a$*$IFOV_b$ - terrain at nadir [m^2] - terrain at the end of scan line [m^2]	1,3 * 2,2 a-along flight 3,1 * 5,1 4,8 * 12,3	2,6 * 1.3 b-along line 16,4 * 8,2 16,9 * 8,7
6 Image size: - number of pixel per line x number of lines - area covered [km^2]	2900*803 = = 2,3 mln 9*5,5 = 50	1800*384 = = 0,7 mln 29,5*3,3 = 97
7 Terrain relief characteristics: - average slope - maximal difference in hight	7° 500 m	1° 50 m
8 Number of points used to form DTM	195	-
9 Total number of reference and control points	166	114

The multivariant computations have been carried out. In this computations various numbers of ground control points and terms of polynomials used for correction have been altered. Chosen results are listed in table 2.

Table 2

Results of correction when various number of control points and terms of correction function are applied

Variant	No. of control points	Form of correction function applied Image A var. 1-5 Image B var. 5-8		RMSE after correction				
				without orientation		ratio a/b	with orientation elements	
				meter	pixel (a)		pixel (b)	meter
Image A								
1	2	without corrections	m_X	82	26,2	5,7	4,6	14,4
			m_Y	139	19,8	3,5	5,7	40
			$m_{X,Y}$	161	32,8	4,5	7,3	43
2	16	Fx_2, Fy_2 formulae(2)	m_X	57	18,1	4,8	3,8	11,9
			m_Y	57	8,1	2,9	2,8	19,8
		fx_2, fy_2 formulae(1)	$m_{X,Y}$	81	19,8	4,2	4,7	23
3	32	Fx_3, Fy_3 formulae(2)	m_X	32	10,2	3,8	2,7	8,6
			m_Y	39	5,5	2,6	2,1	14,7
		fx_3, fy_3 formulae(1)	$m_{X,Y}$	50	11,6	3,4	3,4	18,0
4	64	formulae (1),(2) with $Fx_4 = Fx_3+C_8*X^2*Y^2$	m_X	24	7,6	3,3	2,3	7,1
		$Fy_4 = Fy_3+D_{10}*Y^3$	m_Y	21	3,0	1,7	1,8	12,4
		$fx_4 = fx_3+A_{10}*X^3*Y^2$ $fy_4 = fy_3+B_{12}*X^2*Y^4$	$m_{X,Y}$	32	8,2	2,8	2,9	14,3
5	128	formulae (1),(2) with $Fx_5= Fx_4+C_9*X^4$	m_X	14,3	4,6	2,6	1,8	5,8
		$Fy_5= Fy_4+D_{11}*X^3*Y^5$	m_Y	18,1	2,6	1,7	1,5	10,4
		$fx_5= fx_4+A_{11}*X^5*Y^3$ $fy_5= fy_4+B_{13}*X^3*Y^5$	$m_{X,Y}$	23,1	5,3	2,3	2,3	11,9

Table 2

Image B							
6	2	formulae (2)	m_X 65	3,9	1,2	3,2	53
			m_Y 76	9,1	1,4	6,3	53
		formulae (1)	$m_{X,Y}$ 100	9,9	1,4	7,1	75
7	15	"	m_X 53	3,2	1,7	1,9	32
			m_Y 47	5,6	1,8	3,1	26
			$m_{X,Y}$ 71	6,4	1,8	3,6	41
8	30	"	m_X 32	1,9	1,6	1,2	20
			m_Y 29	3,4	1,9	1,8	15
			$m_{X,Y}$ 43	3,9	1,8	2,2	25

To identify the control points in the image B the line printer was used for generation of quasi half-tone image. The same technique was applied for generation of images shown in Fig.4.

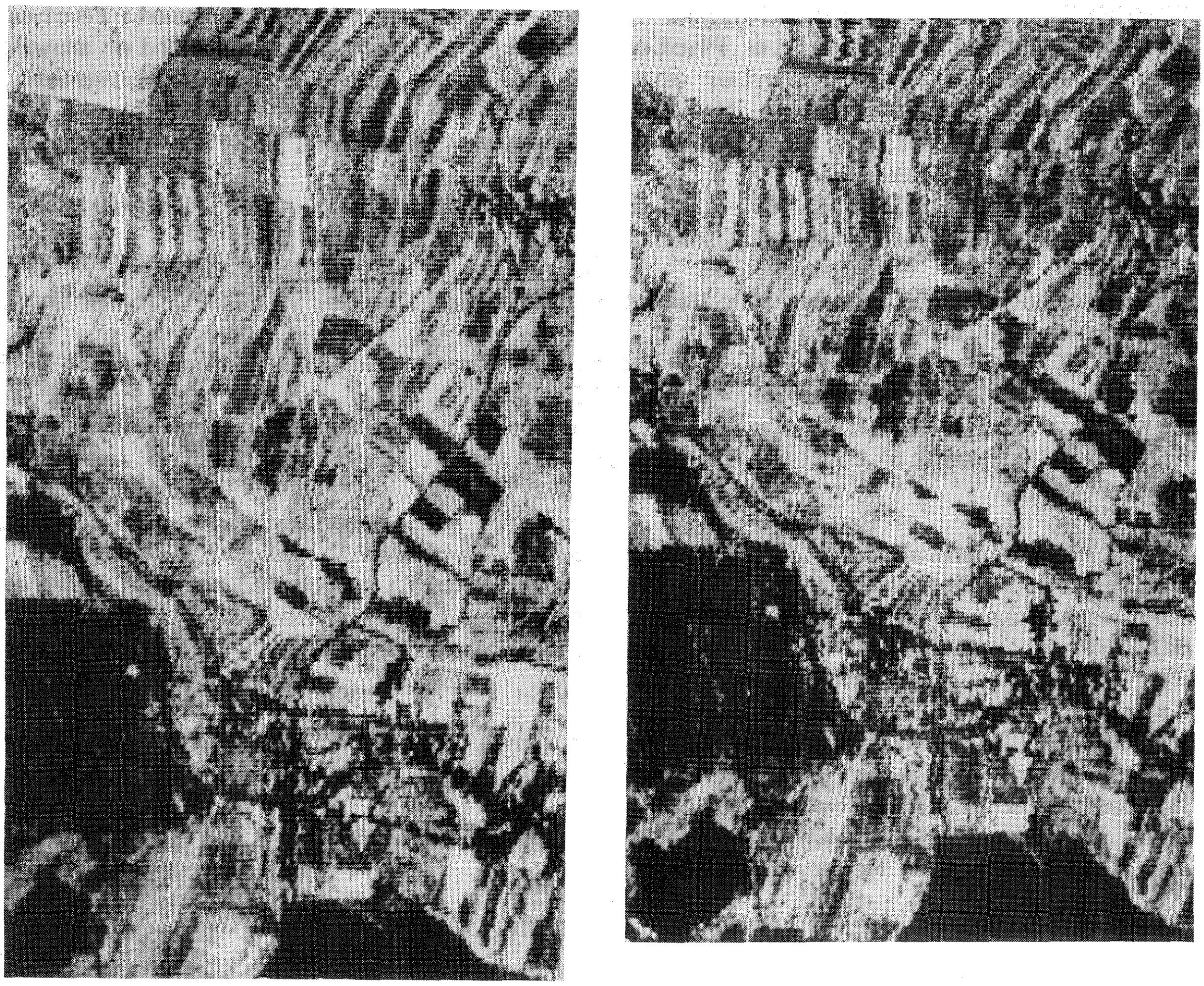

Fig.4 Presentation of original (left) and corrected images

4. Conluding remarks

The procedure confirmed that if more accurate attitude parameters, the fewer ground control points are required.

The errors of the sensor orientation elements measured during the flight are mainly systematic errors and therefore, the correction functions have relatively simple form.

In the proposed procedure either all orientation parameters or only those which strongly affect the image geometry should be applied. In comparison with other procedures which do not use attitude parameters, the number of required control points is reduced twice or even three times delivering the same level of accuracy.

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