FIRST RESULTS OF THE PARAMETRICAL MODEL FOR SATELLITE SENSORS

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ABSTRACT:

In last years digital Photogrammetry and Remote Sensing technology have been quickly developed for mapping and other applications. From 1999 up to now the new era with high resolution satellite imageries, such as Ikonos, QuickBird, EROS, ORBIMAGE opens potentials for producing orthophoto maps in large scale (1 : 5 000 – 1 : 10 000) and update existing topo- maps. It is often necessary to correct these imageries to the same geometric basis before it is possible to use them. This paper presents the parametrical models, developed by authors. It is based on time-dependent collinearity equation of the mathematic relation between ground space and its imageries though parameters describing the sensor position in orbit and of satellite orbit in the geocentric system. Presently, in the Institute of Photogrammetry and Cartography of the Warsaw Technical University, is conducting the research to verify in practice the parametrical model taking into consideration influence of all the parameters and necessary number of photopoints needed for orthorectyfication process of the Ikonos images.

1. INTRODUCTION

In recent years we can observe rapidly increasing interest in the practical application of very high-resolution satellite imaging. The reasons are: from one side a need for satellite information about the surface of the earth to be applied in many different fields, and from the other side a need to achieve digital technologies optional to traditional photogrammetrical solutions (aerial photographs). Poland is particularly interested in taking advantage of satellite imaging type VHRS. This interest results mainly from an urgent need to cover the area of the country with such products as orthophotomaps, DEM or topographic database, in order to reach the same level of coverage as the countries of Western Europe. Therefore it is natural to see in VHRS imaging a source of data quickly reaching this level of coverage. In order to verify practical applications of such imaging, research was conducted, which generating satellite orthophotomaps achieved with a use of our program, obtained from the most commonly used VHR system, i.e. IKONOS-2.

The goal of this research was analyze new model procedures and technologies for producing orthophotomaps based upon the high-resolution satellite images for the selected testing area, which is the area of Warsaw, flat area In the framework of investigations were provided accuracy evaluations of the achieved satellite orthophotomaps in different variants of geometrical correction using algorithm. In this paper is presents detailed assessment of the planimetric accuracy of the panchromatic IKONOS image.

2. KEPLERIAN MODEL FOR HRS IMAGE

Supposed the ground point Q has spatial coordinates X_L, Y_L, Z_L, and X, Y, Z in the local geodetic system $O'X_LY_LZ_L$ and in the geocentric system $OXYZ$, respectively. Its corresponding position q on image taken from elliptic orbit of a satellite S at a time epoch t has coordinates x, y, $-f$ in image system $oxyz$ (Fig. 1). Four angle parameters (elements) that determines orbit position in space with respect to Earth's equatorial plane are angles: i – orbit inclination, Ω – longitude or right ascension angle, w – the argument of perigee and angle ϑ - true anomaly of satellite at a time epoch t. Next two parameters of satellite orbit are eccentricity e and semi-major axis a that define orbit shape and size in space. Satellite position on the given orbit can also be determined by distance r, where r = OO' + O'S = R + H (R – Earth's radius, H – satellite height above a ground) and true anomaly ϑ. We will mark x_{ct}, y_{ct}, z_{ct} - the coordinates of image point that were corrected with the errors of sensor interiors elements taken from calibration and of along-track view angle θ of sensor optical axis such as IKONOS, QuickBird, or across-track view angle α as SPOT 1-4, IRS (Luong and Wolniewicz, 2005a, 2005b, 2006).

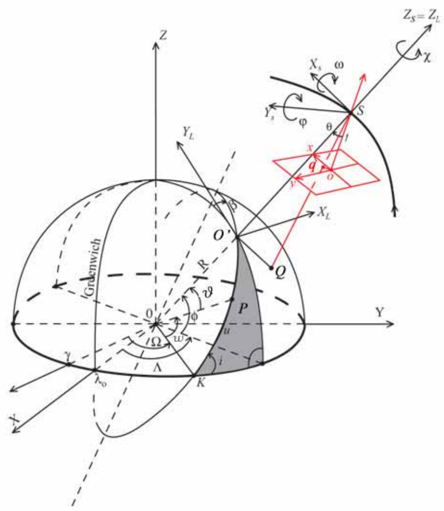

Figure 1. Geometrical relationship between imagery and its terrain in geocentric system OXYZ

On figure 3 the marks mean: γ – vernal equinox, , λ_0 – Greenwich meridian, K – ascending node, P – perigee point, Λ – geocentric longitude, Φ – geocentric latitude.

Basing on the co-linearity condition there is following relation:

$$x_{ct} = z_{ct} \frac{a_1(t)[X - X_S(t)] + a_2(t)[Y - Y_S(t)] + a_3(t)[Z - Z_S(t)]}{a_7(t)[X - X_S(t)] + a_8(t)[Y - Y_S(t)] + a_9(t)[Z - Z_S(t)]} \quad (1a)$$
$$y_{ct} = z_{ct} \frac{a_4(t)[X - X_S(t)] + a_5(t)[Y - Y_S(t)] + a_6(t)[Z - Z_S(t)]}{a_7(t)[X - X_S(t)] + a_8(t)[Y - Y_S(t)] + a_9(t)[Z - Z_S(t)]}$$

where x_{ct}, y_{ct}, z_{ct} - the coordinates of image point x, y that were corrected with the errors of sensor interiors elements ($dx = dx_o + \Delta x$; $dy = dy_o + \Delta y$) and of along-track view angle θ (or across-track view angle α) of sensor optical axis:

$$\begin{bmatrix} x_{ct} \\ y_{ct} \\ z_{ct} \end{bmatrix} = R_{\theta,(or\ \alpha)} \begin{bmatrix} x - (dx_o + \Delta x) \\ y - (dy_o + \Delta y) \\ -(f + df) \end{bmatrix} \quad (1b)$$

with

$$dx = dx_0 + \Delta x = dx_o + \frac{x}{f}df + t_1 x r_a^2 + t_2 x r_a^4 + t_3 x r_a^6 + p_1(y^2 + 3x^2) + p_2 2xy \quad (1c)$$
$$dy = dy_0 + \Delta y = dy_o + \frac{y}{f}df + t_1 y r_a^2 + t_2 y r_a^4 + t_3 y r_a^6 + p_1 2xy + p_2(x^2 + 3y^2)$$

Where: dx_o, dx_o, df - sensor's internal orientation errors; t_1, t_2, t_3 – coefficients charactering error of symmetrical distortion and p_1, p_2 – coefficients charactering error of asymmetrical distortion of optical sensor. For simplification the values dx and dy may be considerably equal to 0.
The coefficients $a_i(t)$ with i = 1, 2, 3,…,9, (in the equation (1a)) – the rotational matrix elements of CCD array line that are the functions of image exteriors orientation elements ω, φ, χ and orbit angles parameters Ω, i, u (where $u = w + \vartheta$) at time epoch t; $X_S(t)$, $Y_S(t)$, $Z_S(t)$ – the coordinates of perspective center S at a time epoch t that are also the functions of satellite orbit parameters. With considering the equation (1a), (1b) new general form for dynamic image taken from elliptic orbit with along-track view angle θ at a time epoch t is:

$$F_{xt}\ (x, f, X, Y, Z, \theta, \omega(t), \varphi(t), \chi(t), i(t), \Omega\ (t), u(t), r(t)) = 0$$
$$F_{yt}\ (y, f, X, Y, Z, \theta, \omega(t), \varphi(t), \chi(t), i(t), \Omega\ (t), u(t), r(t)) = 0 \quad (2)$$

According to (2) each CCD array line has 7 unknown parameters ω, φ, χ, i, Ω, u, r. IKONOS and QuickBird scenes have 3454 and 8656 lines, respectively. There is a large number of unknown parameters to be determined for one scene what practically makes impossible to obtain the solution. In order to solve the eq. (2) unknown parameters are considered as the functions of time t or functions of CCD array lines l based on polynomial form of second order. It means:

$$U_j(t) = \sum_{i=0}^{2} c_{i,j} t^i \equiv \sum_{i=0}^{2} d_{i,j} l^i \quad (3)$$

where $U^T(t) = [\omega(t) \quad \varphi(t) \quad \chi(t) \quad i(t) \quad \Omega(t) \quad u(t) \quad r(t)]$ – the vector of unknown parameters.

Orbital parameters (a, e, i, Ω, w,) can be determined using given position vector $(X_o\ Y_o\ Z_o)^T$ and velocity vector $(v_x\ \ v_y\ \ v_z)^T$ of the satellite (satellite state vector) at the moment t. Inversely, with given orbital parameters satellite's state vector can be calculated.
The difficult problem of using keplerian model is their need to have the raw image with epheremeris data, however some high resolution satellite image vendors do not intend to release these data. They provide users with geo-rectified images (for example IKONOS) with minimum information about the satellite's movement in its orbit. It means the lack of geometry at the time of imaging which makes it very difficult to use keplerian model for geometric correction of these images. Other rigorous methods for solving this problem are further investigating.
In the next section the dynamic affine model that becomes modified from rigorous model for georectified images will be presented.

3. MODEL FOR ORTHORECTYFICATION VHRS IMAGES

Some reasons for selecting the parallel projection model to approximate the rigorous model are:

- The imaging planes are not parallel to each other; therefore, the affine model could experience accuracy degradation when employed in a Cartesian frame.
- Scenes are acquired within very short time, e. g., it is about 0,0015 second per scan line foe Spot; one second for IKONOS scene.
- Narrow field of view (FOV) of scener's optic system. For example, FOV of IKONOS, QuickBird and Spot are 0°93, 2°12, 4° 13, respectively.
- Scenner can be assumed to move with constant velocity. It means the scanner travels equal distances in equal time intervals.
- The sensor's view direction with respect to Earth's ellipsoid normal does not change drastically since satellite's orbital ellipse for the imaging satellite has a focus at the centre of Earth's mass and has a small eccentricity; therefore, the constructed imagery planes retain near-parallelism in a map projection reference system.

Therefore, many scenes, such as IKONOS can be assumed to comply with parallel projection. The relationship between an object space point P(X, Y, Z) and its corresponding scene point p(x',y') (fig. 2) can be written in non-linear form (Morgan et al.) as follows:

$$\begin{bmatrix} x' \\ y' \\ 0 \end{bmatrix} = s.\lambda.R^T \begin{bmatrix} L \\ M \\ N \end{bmatrix} + s.R^T \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ 0 \end{bmatrix} \quad (4)$$

Where: s - scale factor, λ - distance between the an object and image points, L, M, N - components of the unit projection vector in corresponding directions X, Y, Z, with $N^2 = 1 - L^2 - M^2$; Δx, Δy - two shift values; R – rotation matrix between an object and scene coordinate systems.
The geometric parameters of parallel projection is presented in figure 2.

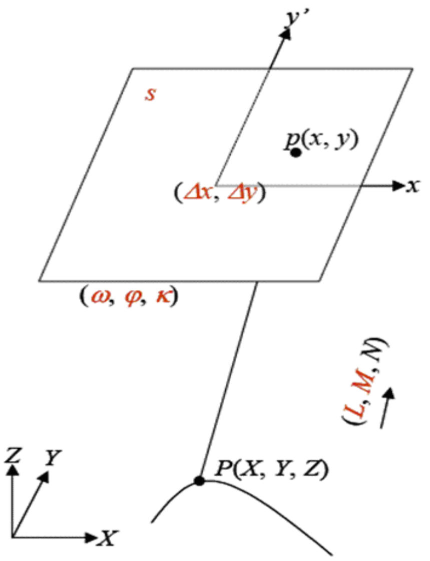

Figure 2. Parameters of parallel projection

Ones provide the linear form of parallel projection is affine model that is described as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} X & Y & Z & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & X & Y & Z & 1 \end{bmatrix} \begin{bmatrix} A_1 & A_2 & A_3 & A_4 & B_1 & B_2 & B_3 & B_4 \end{bmatrix}^T \tag{5}$$

It is known that each scan line captured by push broom sensor are the rigorous perspective geometry. Therefore, for using the parallel projection model the perspective (*x, y*) to parallel (*x', y'*) transformation of scene coordinates are required. There are real relations:

$$\begin{aligned} x' &= x \\ y' &= y\left(\frac{f}{f - y.tg\alpha}\right) \end{aligned} \tag{6}$$

Where: f – scanner principle distance; α – scanner roll angle; x, y and x', y' – image point coordinates in perspective and parallel projection, respectively.

Satellite can dynamically rotes and swings so that sensor can be tilted to desired angle off nadir. A concern arising here in the context of the affine model is the possible introduction of non-linear perturbation as a result of dynamically re-orienting the satellite during image recording. Dynamic variation in pitch angle required special attention it could cause non-uniform resampling. In practice, imagery products are georectified. It means raw images projected to a plane with constant height such as IKONOS, using rigorous geometry model, but perturbation of the sensor might not always be perfectly and completely corrected for in the image. Howere, as an approach to counting for the presence of non-linear image perturbation, tim-variant coefficients arising in affine model can be considered. Supposed the time-variant coefficients in affine model are linear with respect to the number of scan lines, the final dynamic sensor model for georectified image is described by following forms:

$$\begin{aligned} x &= \frac{T_{01}}{1 - T_{11}} \\ \left(\frac{f}{f - y.tg\alpha}\right).y &= \frac{T_{01}}{1 - T_{11}} T_{12} + \frac{T_{02}}{1 - T_{11}} - \frac{T_{02}}{1 - T_{11}} T_{11} \end{aligned} \tag{7}$$

Where: T_{01}, T_{02}, T_{11}, T_{12} – affine models.
The model (7) will be an object of following experiment.

4. EXPERIMENTS

4.1 Data presentation

The scenes achieved by the systems IKONOS. For flat area the deflection from axis in relation to nadir point are 6.5 degrees for IKONOS. Precise characteristics of the imaging used have been presented in table.

In order to realize the process of ortho-adjustment, we presumed a photogrammetry matrix with the use of a GPS system. For determining coordinates of these points a TRIMBLE 4700 satellite dual-frequency receiver with Micro-centere antenna was used. The survey was done with a use of the fastatic method with an accuracy 0.1 m in the terrain for the values of x, y and z. During the survey, the terrain points were documented with photographs, on which the terrain situation and survey position were visible. They were used together with photographic sketches for pointing out the points on images. The process of determining future points to be used for correlation and for controlling mapping quality of the achieved points constituted a very important element. In each case we tried to ensure that the accuracy of GCP identification on the imagery was definitely below one pixel.

Imaging data	IKONOS Warsaw
Date of acquiring	2003/08/06
Hour of imaging	10:01
Scene number	2003080610015550000011323057
Type of product	Geo Ortho Kit
Off nadir angle [degrees]	7
Radiometric resolution	11
Resolution	1.0
Scene size [km]	11 x 18

Table 1. Characteristics of image used

4.2 Accuracy analysis

Ortho-adjustment process were conducted using our dynamic model . The Parametrical model describes actual relations between the land and its image, therefore the terms of this model have a precise geometrical interpretation. The basis for construction of the precise model for satellite imaging is the condition of co-linearity. In this point, however, it may be applied not to the entire image, but only to a single line. Parametrical models are less susceptible to photo-points distribution and possible errors in data. The table presents the achieved accuracy of ortho-adjustment depending on a number of GCP points. Achieved accuracy was checked on controlling points, which did not take part in the process of ortho-adjustment. In the framework of each scene we checked upon the accuracy achieved on controlling points (CP) in number 20. Table no. 1, example for variant 12 GCP/20CP refers to the method of simultaneous calculation of coordinates (X,Y) of ground control points: a/ Column 2: prior to elimination of systematic error (angle θ); b/ Column 3: a\ after elimination of systematic error in consideration of angle θ; c/ Column 4: after elimination of systematic error due to dynamic shift; d/ Column 5: Final errors

No. of GCP	Real errors prior to elimination of systematic error		Real errors after elimination of systematic error in consideration of angle θ FOV (Field of view)		Real errors after elimination of systematic error due to dynamic shift		Real errors after elimination of systematic error first in consideration of angle θ FOV and due to dynamic shift	
	Ex	Ey	Ex	Ey	Ex	Ey	Ex	Ey
3A	19,70	-0,65	-4,76	-0,65	-2,63	0,71	-0,98	0,71
5A	21,72	-1,26	-3,56	-1,26	-0,61	0,10	0,22	0,10
6A	21,21	-1,25	-3,25	-1,25	-1,12	0,12	0,53	0,12
7A	21,60	-1,49	-2,58	-1,49	-0,73	-0,13	1,19	-0,13
8A	18,60	-1,64	-3,65	-1,64	-3,72	-0,28	0,12	-0,28
9B	21,37	-1,65	-3,35	-1,65	-0,95	-0,29	0,42	-0,29
10B	21,46	-0,75	-3,27	-0,75	-0,87	0,61	0,51	0,61
11A	21,35	-1,34	-3,38	-1,34	-0,98	0,02	0,39	0,02
13A	20,83	-2,02	-2,80	-2,02	-1,50	-0,66	0,98	-0,66
14A	20,22	-1,79	-3,96	-1,79	-2,11	-0,42	-0,19	-0,42
15B	21,72	-0,53	-3,83	-0,53	-0,60	0,83	-0,05	0,83
16A	21,11	-1,19	-3,90	-1,19	-1,22	0,18	-0,12	0,18
17B	21,16	0,41	-4,67	0,41	-1,16	1,77	-0,89	1,77
18A	22,46	-0,90	-3,36	-0,90	0,14	0,46	0,41	0,46
19B	21,98	-2,49	-4,95	-2,49	-0,35	-1,13	-1,17	-1,13
22A	25,33	-0,82	-3,24	-0,82	3,01	0,54	0,54	0,54
23A	24,37	-2,99	-3,65	-2,99	2,05	-1,63	0,12	-1,63
26B	27,28	-0,48	-4,04	-0,48	4,95	0,89	-0,27	0,89
27B	26,28	-1,67	-4,77	-1,67	3,95	-0,31	-0,99	-0,31
28B	26,77	-2,74	-4,56	-2,74	4,44	-1,38	-0,78	-1,38
RMS	**22,45**	**1,58**	**3,83**	**1,58**	**2,33**	**0,80**	**0,66**	**0,80**

Table 2. example for variant 12 GCP/20CP refers to the method of simultaneous calculation of coordinates (X,Y) of ground control points.

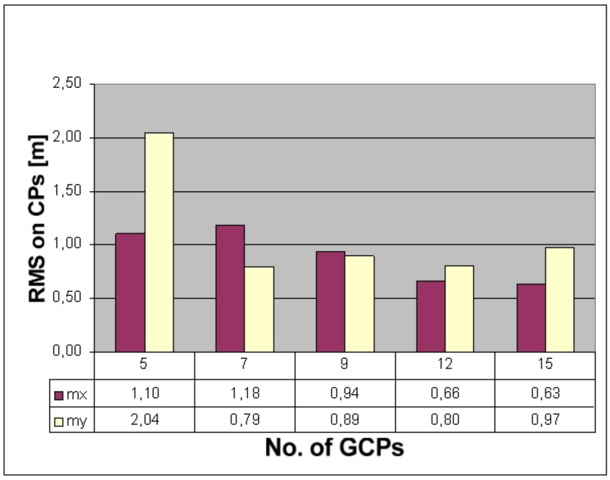

Figure 3. Diagram of relation between the mean errors for determined points and a number of photo-points for the method of simultaneous calculation.

5. CONCLUSION

The model used enables IKONOS ortho-adjustment for different numbers of GCP and available DTM, and to achieve accuracy in VHR ortho-adjustment process of nearly 1 meter. At the same time we have to be very strict when determining the following:

a. GCP points should be very precisely selected, measured and interpreted in the process of ortho-adjustment.
b. The test show that the parametric models demonstrating error stability for IKONOS orthorectification, with min. 5-12 of GCP.
c. The geometric limitation is determination of satellite parameters.

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