EVALUATING ACCURACIES OF PARAMETRICAL AND RPC MODELS FOR ORTHORECTIFYING VHRS IMAGERIES

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ABSTRACT

In the last years Very High Resolution Satellite (VHRS) images such as IKONOS, QuickBird, OrbView, EROS, SPOT 5, etc., have been more and more widely used for different purposes, in particular suitable to investigate the climatic changes, natural risks such as floods, earthquakes, etc. Orthomap of 1:5 000 scale with Ground Sampling Distance (GSD) of 0,5m from VHRS images is one of three important sources for establishing GIS together with Digital Elevation Model (DEM) of ±1,0m in height error and topographic map of 1:10 000 scale. Therefore, the accuracy of orthomap affects on GIS reliability. Orthorectification accuracy of VHRS imagery is dependent on three essential factors: sensor geometrical models used for orthorectifying (software system); the features of Ground Control Points (GCP) and DEM/DTM accuracies. The content of this paper deals with the accuracy investigation of two geometric models so-called parametrical (or physical) and RPC (Rational Polynomial Coefficients), installed in the commercial ImageStation, realized for orthorectifying VHRS imageries. Obtained accuracies of orthorectifcating VHRS imagery as IKONOS and QuickBird presented in the paper have important means for practical application of producing digital orthomaps.

1 INTRODUCTION

From 1999 up to now the new era with Very High Resolution Satellite (VHRS) imageries as IKONOS, QuickBird, EROS, OrbView, has been in potential for producing orthophoto in large scale (1:5 000- 1: 8 000), to update existing maps or to compile general-purpose or thematic maps (*Jacobsen, 2003*). The understanding of geometrical models of VHRS image is very important for improve orthorectification process. An overview about different models of VHRS image such as parametrical and Rational Polynomial Coefficient (RPC) model will be presented in this paper.

Parametrical (or physical) model describes directly strict geometrical relations between the terrain and its image basing on the co-linearity condition. However, in this case we may apply it not to entire image, but just to a single line. The orientation elements of single lines are the functions of time. They can be determined on the basis of the Ground Control Points (GCPs) (*Luong and Wolniewicz, 2005, 2006; Michalis and Dowman, 2005*).

The purpose of a replacement camera model is to provide a simple, generic set of equations to accurately represent the ground to image relationship of the physical camera. In the sections that follow we will describe the RPC camera models of high resolution satellite that represented the indirect relation between terrain and its image acquired on the flight orbit (*Grodecki et al., 2004; Tao et al., 2001*).

This paper, at first, presents two general mathematical models so-called parametrical and RPC models. Next, in the third section the characteristics of IKONOS, QuickBird imageries and test field of our experience have been presented. At the and of third section the results obtained from orthorectification process of IKONOS and QuickBird become analyzed and evaluated. The research results given in this paper are taken from our project Nr 5 T12E 00724 (*Wolniewicz et al., 2005*).

2 BASIC OF PARAMETRICAL AND RPC MODELS

2.1 Parametrical model

Having the 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, the ground point Q owns its corresponding position on image with coordinates x, y, $-f$ in image system $oxyz$ at a time epoch t of a satellite S on elliptic orbit (Fig.1). Three parameters (elements) of orbit position in space with respect to Earth's equatorial plane are the angles i – the orbit inclination, Ω – the longitude or right ascension angle and w – the argument of perigee. At a time epoch t the angle ϑ (true anomaly of satellite), the eccentricity e and semi-major axis a stand next parameters of satellite orbit, where magnitude e and a define its shape and size.

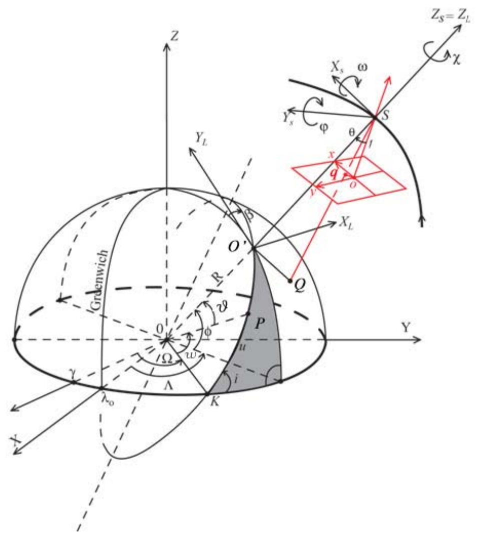

Figure 1. Relationship between imagery and Earth in geocentric reference system

Satellite position on the given orbit can also be determined by polar coordinates of ϑ – true anomaly and distance r, where r = OO' + O'S = R + H (R – Earth's radius, H – satellite hight above a ground). We will mark x_{ct}, y_{ct}, z_{ct} - the coordinates of image point that were corrected with the errors of sensor interiors elements and of along-track inclination angle of sensor optical axis such as IKONOS, QuickBird, or cross-track angle as SPOT 1-4, IRS.
In figure 1 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:

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

where $a_i(t)$, i = 1, 2, 3,…,9 – the rotational matrix elements of CCD array line and orbit angles ω, φ, χ, Ω, i, $u = w+\vartheta$ at epoch t; $X_S(t)$, $Y_S(t)$, $Z_S(t)$ – the coordinates of perspective center S at epoch t. It is clear that a_i , X_S , Y_S, Z_S are the functions of image exteriors orientation elements and orbit elements, respectively, at an epoch of a time t.
The equation (1) has now new general form:

$$
\begin{aligned}
&F_{xt}\,(x_{ct}, z_{ct}, X, Y, Z, \omega(t), \varphi(t), \chi(t), i(t), \Omega\,(t), u(t), r(t)) = 0\\
&F_{yt}\,(y_{ct}, z_{ct}, X, Y, Z, \omega(t), \varphi(t), \chi(t), i(t), \Omega\,(t), u(t), r(t)) = 0
\end{aligned}
\qquad (2)
$$

IKONOS and QuickBird have 3454 and 8656 lines, respectively. There are a lot of unknown parameters to determine for one scene. It is no real solution in practice. It is better to solve the eq. (2) when the unknown parameters are considered as the functions of time t or functions of CCD array lines l in the polynomial form of second order. It means:

$$U(t) = \sum_{i=0}^{2} c_i t^i \equiv \sum_{i=0}^{2} c_i l^i \qquad (3)$$

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

2.2 RPC model

The purpose of a replacement camera model is to provide a simple, generic set of equations to accurately represent the ground to image relationship of the physical camera. We might write that relationship as $(x,y) = \mathbf{F}(B,\ L,\ H\ )$ where **F(.)** is the replacement camera model function, $(x,\ y)$ is an image coordinates, and $B,\ L,\ H$ is a ground coordinates.

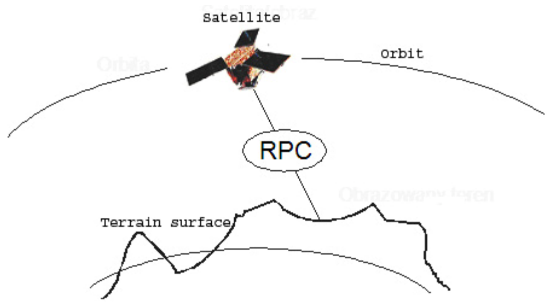

Figure 2. RPC model of geometric relationship between imagery and Earth's surface

The RPC coefficients describe a single image from a particular imaging system. For this model, image vendors describe the location of image positions as a function of the object coordinates (longitude, latitude) by the ration of polynomials:

$$x_{ij} = \frac{F_{i1}\ (B,L,H)_j}{F_{i2}\ (B,L,H)_j}; \qquad y_{ij} = \frac{F_{i3}\ (B,L,H)_j}{F_{i4}\ (B,L,H)_j} \qquad (4)$$

where x_{ij} , y_{ij} - normalized image coordinates; $B,\ L,\ H$ - normalized the latitude, longitude, height; and the polynomial $F_i(.)$ has the following general form (5). Normalized values are used intend of actual values in order to minimize numerical errors in the calculation.

For example, each polynomial is up to third order in $(B,\ L,\ H)$, having as many as 20 terms in the form:

$$F_i(B,\ L,\ H\ ) = C_1 + C_2L + C_3B + C_4H + C_5LB + C_6LH + C_7BH + C_8L^2 + C_9B^2 + C_{10}H^2 + C_{11}BLH + C_{12}L^3 + C_{13}LB^2 + C_{14}LH^2 + C_{15}L^2B + C_{16}B^3 + C_{17}BH^2 + C_{18}L^2H + C_{19}B^2H + C_{20}H^3 \qquad (5)$$

Substituting $F_i(.)$ in Equation (4) with the polynomials in Equation (5) and eliminating the first coefficient in the denominator, we have a total of 39 coefficients in each equation.

3 EXPERIENCE PRESENTATION

3.1 Test field and image data

Two test fields „WAR" and "NOTAR" in Poland (*Wolniewicz et al., 2005*) belong to flat and mountainous ground surface, respectively. The test field WAR is a part of WARSAW city, has terrain undulation no larger than 80m. The test field NOTAR is a part of NOWY TARG district with terrain undulation up to 600m. For each test field „WAR" and "NOTAR" we have IKONOS and QuickBird scenes with their parameters presented in the table 1. Four parts of IKONOS and QuickBird of WAR and NOTAR fields are in figure 3.

In the test fields WAR and NOTAR there are 17 and 27 Independent Control Points (ICPs) used for analyzing the accuracies of orthorectification process, respectively.

Table 1. The parameters of VHRS imageries of test fields „WAR” and “NOTAR”

Parameter	IKONOS- 2		QuickBird - 2	
	Test field WAR	Test field NOTAR	Test field WAR	Test field NOTAR
Date of imaging	29-04-2003	17.06.2003	4-05-2003	03.10.2003
Time of imaging	9:55 GMT	10:03 GMT	9:35 GMT	9:22 GMT
Inclination angle	10,5°	14°	5,1133°	12°
Type of image	PAN/MS	PAN	PAN	PAN
Image product	Geo Ortho Kit	Geo Ortho Kit	Basic 1B	Basic 1B
Pixel size GSD	1m	1.0m	0,61m	0.64m
Image size [km]	11,5km x 21km	11,5km x 9km	16km x 16km	16km x 16km
Percent of cloud	0%	0	2%	0

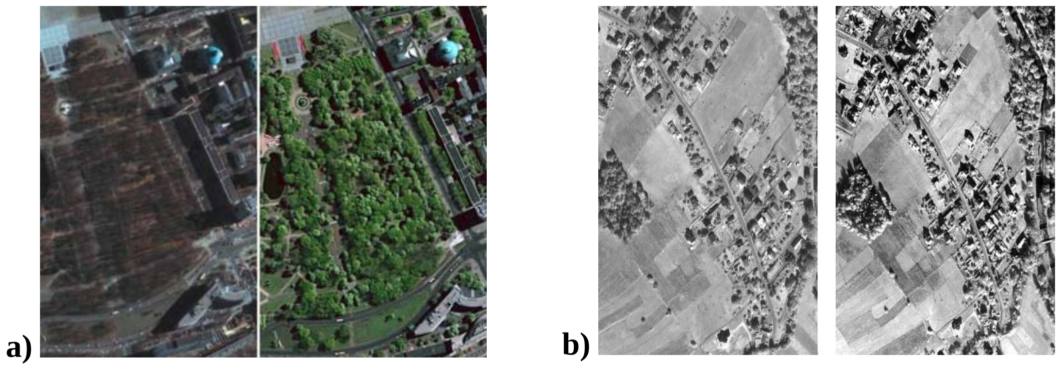

Figure 3. Four parts of VHRS imageries: Test field WAR (a): IKONOS (left), QuickBird (right); Test field NOTAR (b): IKONOS (left), QuickBird (right)

3.2 Results and analysis

The software module of parametrical model installed in the PCI Geomatica System (Canada) has been used. First DEMs of both test fields WAR and NOTAR was created from DGPS with height error of ±0,2m. Second DEM of test field NOTAR was taken from DTM data with the spacing of square net of 30mx30m and the height error of ±4,0m. Figure 4 presents the Root Mean Square Errors (RMSE) of ICP position after orthorectifying by parametrical model for IKONOS and QuickBird imageries. The abscissa axes on the figures present the number of Ground Control Points (GCP) used in orthorectifying. Similarly, figures 5 describes the Root Mean Square Errors RMSE of ICP position after orthorectifying by RPC model for same imageries.

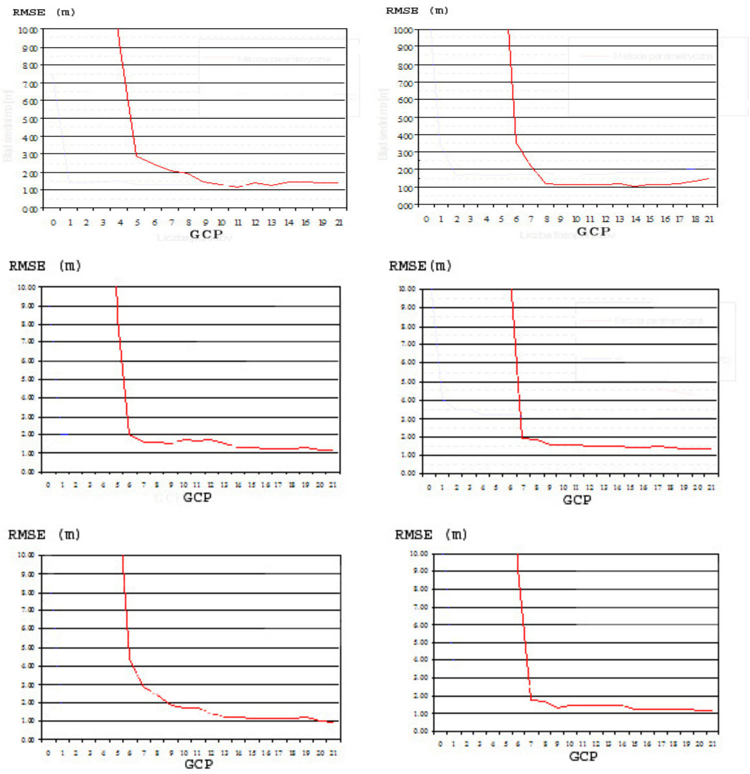

Figure 4. Accuracy of IKONOS (left), QuickBird (right) orthorectified with parametrical model: Top - for test field WAR using coordinates Z taken from DGPS; Middle - for test field NOTAR using coordinates Z taken from DGPS; Below - for test field NOTAR using coordinates Z taken from DTM

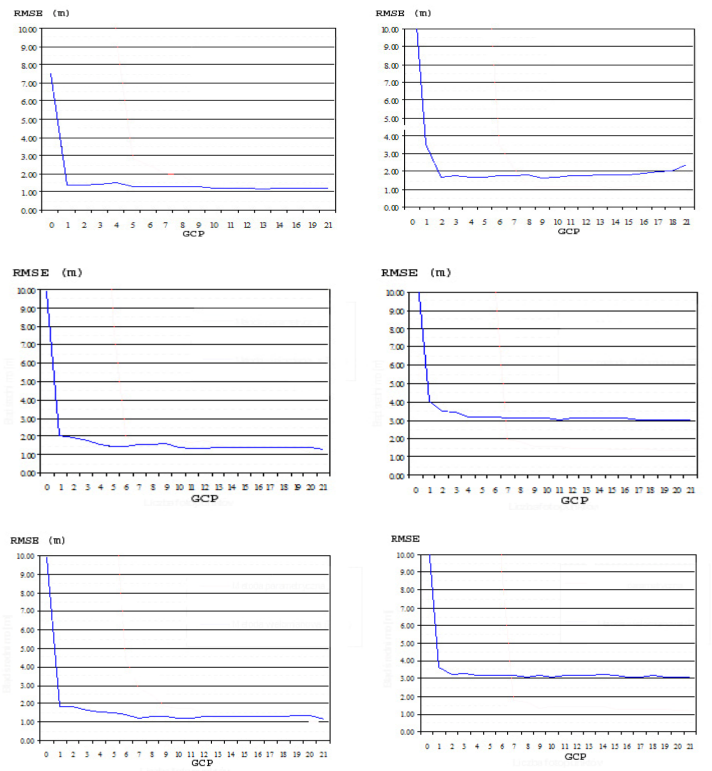

Figure 5. Accuracy of IKONOS (left) and QuickBird (right) orthorectified with RPC model: Top - for test field WAR using coordinates Z taken from DGPS; Middle - for test field NOTAR using coordinates Z taken from DGPS; Below - for test field NOTAR using coordinates Z taken from DTM

From obtained results presented on the fig. 4, 5 we can come to some conclusions: To receive the position errors of ±1,0m to ±1,5m for IKONOS imagery of both flat and mountainous terrain the number of GCP needed to orthorectifying by parametrical and RPC model are minimum 8 and 3 points, respectively. QuickBird imagery has the same errors as IKONOS only for flat terrain using parametrical model. The RPC model is not effectively used for QuickBird even in flat terrain.

Orthomaps generated from VHRS images have very important practical uses. Figure 6 presents actual land state extracted on orthomap of 1:5000 scale, created from QuickBird of certain agricultural region in Poland. Parcel borderlines have been extracted and registered in digital form that is principle database of cadastral map for managing urbanities.

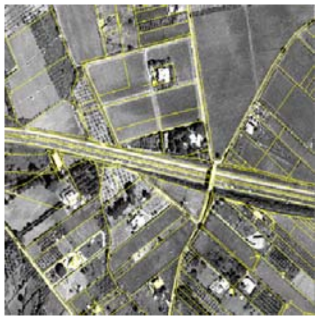

Figure 6. Actual land state extracted on orthomap (1:5000) acquired from QuickBird

4 CONCLUSION

The RPC model is simple one that does not require the given data of imaging sensor and orbit elements. This model is effectively used for orthorectifying IKONOS imageries of both flat and mountainous terrain with available accuracies up to ±1,5m. Using the coefficients of RPC model supplied by imagery distributor the number of GCP needed to orthorectifying is minimum 3. Basing on the experimental results is that IKONOS can be used to creating orthomap in the scale 1:8000.

The parametrical model is a rigorous model basing on the co-linearity condition and requiring the given data of satellite orbit elements. This model is good for QuickBird imagery of both flat and mountainous terrain. The RPC model can be used for QuickBird imagery of flat terrain but not good for terrain with large undulation. Orthomap of 1: 5 000 scale from QuickBird can be generated for database of GIS.

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