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Accuracy assessment of DSM extracted from IKONOS stereo images

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ABSTRACT: Practical applications of 3D used in modern cartography even more frequently take advantage of the Very High Resolution Satellite (VHRS). The most commonly known example is the first VHRS system called IKONOS (1m resolution) that has been operating on the orbit since 1999. This system permanently collaborates with the receipt-and-transmission station type Regional Operation Center (ROC) situated on the territory of Poland, the Satellite Center for Regional Operations (SCOR). From the other hand, the greatest achievement of the contemporary satellite photogrammetry is the elaboration and precise application of Rational Function Model (RFM), which can describe information about orientation of VHRS systems. RFM is the sensor model of IKONOS imagery where vendors provide Rational Polynomial Coefficients (RPC).

This paper describes an experiment being in progress, which refers to the accuracy analyses (3D geo-positioning using stereo IKONOS along-track images) obtained for the north-western areas of Krakow. Taking advantage of RPC data delivered along with the images, and of commercial software, such as ERDAS, one evaluated the accuracy of the results obtained. In order to generate 3D one used 31 GCP-ICP measured with a differential GPS static technique providing for 10 cm planimetric and 20 cm vertical accuracy. The results obtained were compared with available DEM obtained from SRTM and DTED L2. They were then analyzed with a use of ICP from GPS measurements. One presented the detailed conclusions and recommendations for future surveys with a use of other VHRS systems, 3D adjustment methods, and in particular other rigorous modeling approaches, and attempts to use 3D Affine projection model for the stereo images. Final conclusions allow for determining the optimal foundation for stereo IKONOS imagery effective process that can provide sub-meter 3D geo-processing accuracy.

1 INTRODUCTION

Provided by Space Imaging Inc (present by GeoEye), IKONOS imagery is the first - one meter commercially available. The IKONOS system collects 81-95 centimeter – resolution stereo panchromatic and 3.24-3.80 meter multi – spectral images. GeoEye provides 5 different image products (Space Imaging 2005), based on processing levels:

Geo, Reference, Pro, Precision and Precision Plus with associated accuracy: 25 m, 11.8 m, 4.8 m, 1.9 m, 0.9 m.

The Geo imagery product is the last processed of the IKONOS type of data. It has been designed for the users possessing an opportunity for the top accuracy of geometrical adjustment process execution. Using this kind of product, it is possible to effect ortho-adjustment both with an application of a rigorous sensor models and the rigorous camera models, a so-called RFM. RFM describes elements of positioning with a use of information delivered by vendors, which is included in RPC coefficients (Tao and Hu 2001).

The IKONOS satellite image vendors, computes the rational polynomial coefficients (RPC) for each image and distributes it with raster data. In other words, with a use of the polynomial coefficients one can determine the relations between the coordinate system of an image and the position of the field object shown in equation no. 1.

$$x = \frac{p_1(X,Y,Z)}{p_2(X,Y,Z)} = \frac{\sum_{i=1}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} a_{ijk}X^iY^jZ^k}{\sum_{i=1}^{n1}\sum_{j=0}^{n2}\sum_{k=0}^{n3} b_{ijk}X^iY^jZ^k} \quad y = \frac{p_3(X,Y,Z)}{p_4(X,Y,Z)} = \frac{\sum_{i=1}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} c_{ijk}X^iY^jZ^k}{\sum_{i=1}^{n1}\sum_{j=0}^{n2}\sum_{k=0}^{n3} d_{ijk}X^iY^jZ^k} \tag{1}$$

Where the polynomial Pi (i = 1, 2, 3, and 4) has the following general form:

$$\begin{aligned} P(X,Y,Z) = {} & a^1 + a_2X + a_3Y + a_4Z + a_5XY + a_6XZ + a_7YZ + a_8X^2 + a_9Y^2 + a_{10}Z^2 \\ & + a_{11}XYZ + a_{12}X^3 + a_{13}XY^2 + a_{14}XZ^2 + a_{15}X^2Y + a_{16}Y^3 + a_{17}YZ^2 \\ & + a_{18}X^2Z + a_{19}Z + a_{20}Z^3 \end{aligned} \tag{2}$$

And where (x, y) are the column and row of each image point and (X,Y, Z) ground point. For each image, 80 rational polinomial coefficients (a_{ijk}, b_{jk}, c_{ijk}, d_{ijk}), m_1, m_2, m_3, n_1, n_2, n_3 are 0–3, where $i + j + k \leq 3$.

For RPCs, when we talk about the adjustment of the first level, we take into consideration an influence of distortion due to optical projection, while for the second level we take into consideration an influence of the Earth curvature, refraction of an atmosphere and distortion of an optical system. Other and more advanced aspects affecting the imaging distortion are eliminated on the third level when we use RFM. The standard approach is to use RPC method without GCP. Using exact data in form of GCP we talk about enhancing the ground accuracy (Li 2003).

The goal of this research is the verification of RFM for IKONOS stereo imagery for the production of large scale DSM and ortho-images using commercial programs.

The main goals of research works were as follows:

– Designing the research field and acquiring stereo pair for IKONOS scenes,
– Analyze and learn the mathematical models used for generation of DSM,
– Design and measure the photogrammetric matrix (GCP –ICP),

– Analyze the influence of a quantity and distribution of GCP for the model type RFM,
– Verify the quality of the obtained DSM in relation to the available data type SRTM and DTED.

2 EXPERIMENT

A stereo pare of IKONOS, was acquired on 25.06.2005 for this experiment, and SCOR was also supplied with RPC for both imagery with GSD 0.8 m. North – West part of Krakow was selected as different ground feature and variety of topography. Figure 1 shows the selected study area within the IKONOS footprint over Krakow.

The selected areas are around 23.3 km long by 12.4 km wide covering an area about 300 sq. km in the north – west part of Krakow. Normal collection azimuth and normal elevation angle of satellite was used for calculating convergent angle (see Table 1). Overlapping was 97.3%.

In order to realize the process of 3D geopositioning, 31 GCPs were used for processing with an accuracy of about 10 cm planimetric and 20 cm vertical. The height of the ground points range from 244 m to 429 m. During the survey, the terrain points were documented with photographs, on which the terrain situation and survey position were visible. The process of determining coordinates future points to be used for correlation and for controlling 3D geopositioning accuracy. In each case we tried to ensure that the accuracy of GCP identification on the imagery was definitely below one pixel.

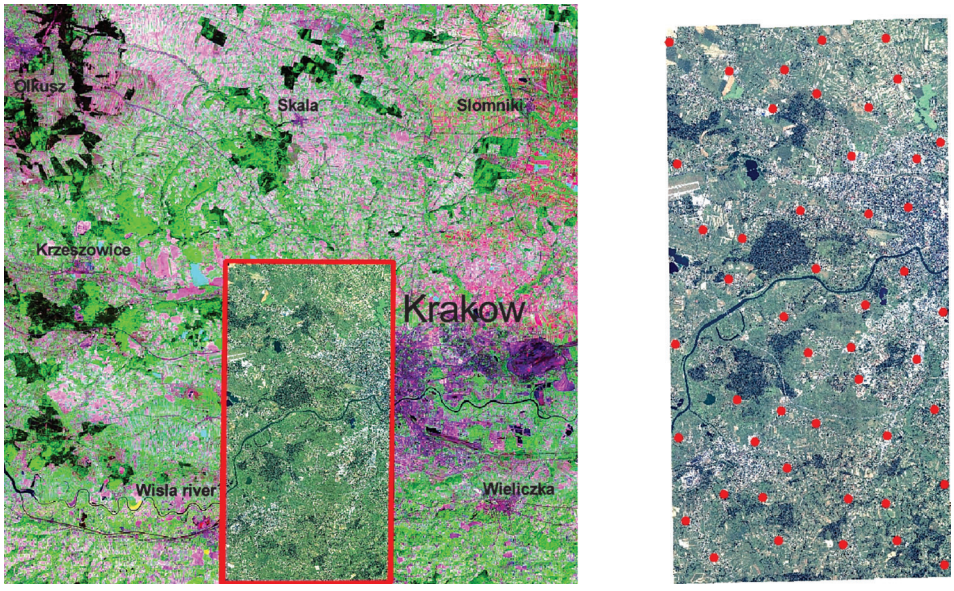

Figure 1. Footprint of IKONOS stereo over Krakow and distributing of GCP and ICP on images.

Table 1. Parameters of IKONOS stereo images used in the experiment.

	Forward	Backward
Acquisition data & time (GMT)	2005-06-25 09:59	2005-06-25 10:00
Image size (row * columns)	30444* 16224	29091*15502
Collection azimut (θ)	359°.0610	223°.7498
Collection elevation (α)	69°.06408	76°.87305
Cross Scan (GSD)	0.87	0.85
Along Scan (GSD)	0.94	0.86
Sun Angle Azimut	157°.71	158°.11
Sun Angle Elevation	62°.13	62°.17
Convergence angle (δ)	31°.59	

3 ACCURACY OF DSM GENERATED FROM STEREO IKONOS DATA

We acquired DSM from IKONOS stereo images with a use of the RFM, based upon commercial software – ERDAS. Uniform distribution of adjustment points was presumed. Figure 3 presents a specification of acquired accuracy of generated DSM on a number of GCP points. The achieved accuracy was checked on control points (ICP), which did not take part in the process of DSM generation.

The results of the experiment with the RFM model for IKONOS stereo images, without any control points, showed a horizontal accuracy of 3 m and vertical accuracy of 7 m. When using GCP with RFM model, the accuracy is improved to 1.2 m in horizontal, and 2 m in vertical accuracy. However, both were compatible with results published by Space Imaging for Reference Stereo product which are 3.0 m horizontal accuracy and 6.4 m vertical accuracy (Dial and Grodecki, 2003).

4 DISCUSSION AND CONCLUSIONS

In this research, one IKONOS stereo pair, we compared the three-dimensional geopositioning accuracy of the different combinations using number of GCP. All results were presented on ICP.

Unfortunately the RPCs are affected by a constant shift and hence are not very accurate, so they have to be refined by using GCP. Through generation of DSM from IKONOS stereo images using RFM in commercial software we can achieve accuracy RMSz 2 m.

1. The RFM model using RPC files supplied by vendors, can be used for stereo orientation and DSM generation without GCP; then vertical accuracy is about 7 m.

Table 2. Comparison of RMS over up to 30 ICP of RFM Model.

Number of GCPs points	0	5	10	15	18	21	25
RMSe on check points [m]	7, 7	3, 8	3	2, 7	2, 39	2, 14	2, 01

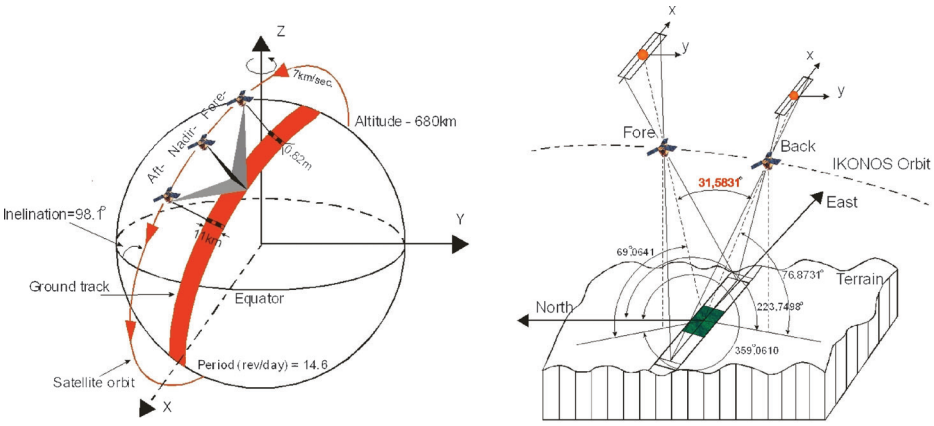

Figure 2. Orbital Geometry (a) and parameters of data along-track IKONOS stereo images (b).

2. Using RPCs files with more GCP we received better accurate results.
3. IKONOS stereo data with well distributed GCP can be used for generated DSM with accuracy RMSz 2 m.
4. DSM generated from IKONOS is compatible with DTED L2 and SRTM.
5. In the along-track direction, a greater convergent angle will give better accuracies.
6. GCP points should be very precisely selected, measured and interpreted in the process of DSM generated.
7. In the next step in the experiment will be to compare the results with other commercial software and using 3D Affine projection model.
8. Rigorous mathematical models for stereo VHRS images need to be developed and compared with RFM Models.

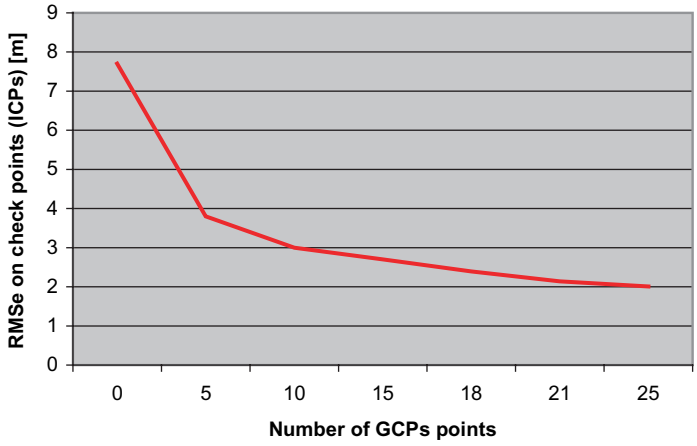

Figure 3. Accuracy of IKONOS Stereo Imagery for KRAKOW area.

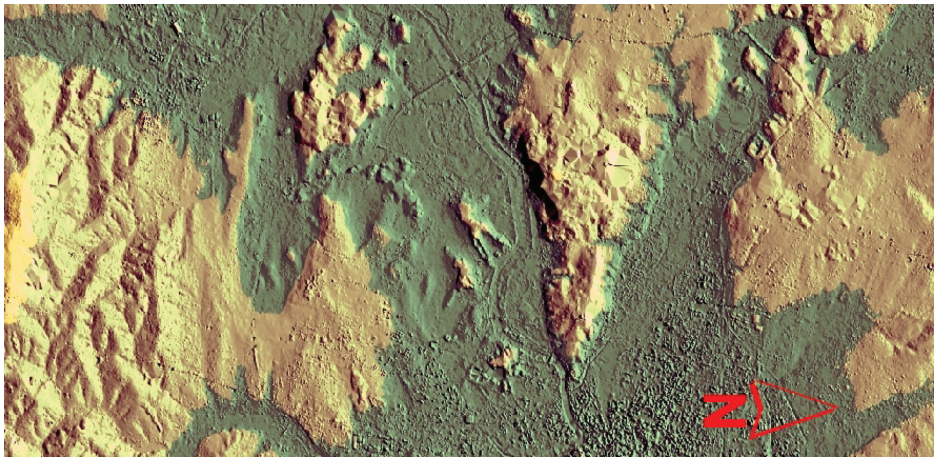

Figure 4. DSM of the case study over Krakow (Poland) generated from IKONOS stereo images.

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