ASSESSMENT OF DSM ACCURACY OBTAINED BY HIGH RESOLUTION STEREO IMAGES

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ABSTRACT:

The high-resolution satellite systems are more and more commonly providing products obtained in a stereoscopic models. This type of stereoscopic images, usually obtained from a single orbit becomes widely used in generating precise Digital Surface Model (DSM). At present, a number of commercially available software provides algorithms allowing for almost automatic generation of DSM and Digital Elevation Model (DEM). Since the development of specialist satellite systems designed mainly for supplying this type of products and provided with a double optical system (e.g., Cartostat), interest in their capabilities is continuously growing. This paper discusses a possibility of generating DSM by using widely available, commercial software. The experiment has been performed using images received from the systems IKONOS and Cartostat. The following software has been used: PCI Geomatica 10, ERDAS Imagine 8.7, Leica Photogrammetry Suite 9 and Photomod 4.1. The impact of the number of GCP involved in the DSM generating process on the mean error with respect to obtained elevation values has been assessed. The DSM generation process (with increasing number of GCP) has been preformed in the same way, disregarding the software used. Ground Control Points (GCP) and Control Points (CP) for the experiment have been designed and measured using GPS systems. Moreover, problems and errors found while using the commercially available software allowing for generation of DSM have been discussed.

1. INTRODUCTION

In 1986 on its orbit appeared SPOT 1, a satellite designed specially to acquire stereo images from neighboring orbits. This placement enabled for construction of the ground digital models with a use of satellite images.
Actually, the VHRS systems such as IKONOS and QuickBird, besides making panchromatic and multi-spectral images are also capable of acquire stereo-images. Elaboration of the very high resolution satellite images opens this opportunity for re-establishment and mastering methods for automated generation of DSM used formerly in traditional photogrammetry.
In this article we present the results of automated process of generation of DSM with a use of the following commercial software: PCI Geomatica 10, ERDAS Imagine 8.7, Leica Photogrametry Suite 9 and Photomod 4.1. In order to conduct an experiment, one selected images coming from IKONOS system operating already for more than 7 years, and from recently launched to the orbit Cartosat–1 satellite. The selected test fields for images from IKONOS comprise eastern part of Krakow agglomeration (mountain area), while for images Cartosat-1, the south-west part of Warsaw – Rawa Mazowiecka (flat areas).

2. TEST FIELD – KRAKOW

2.1 Characteristics of IKONOS images

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

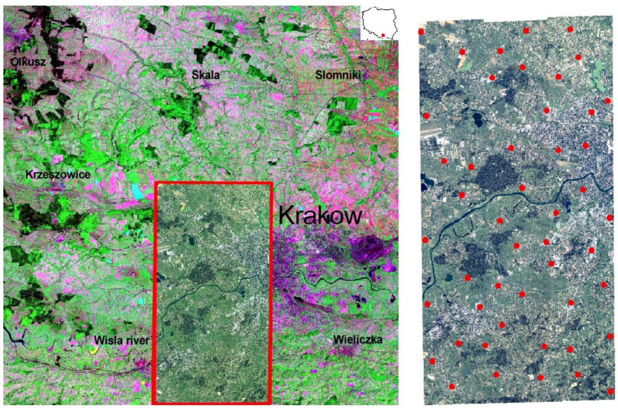


Figure 1. Footprint of IKONOS stereo over Krakow and distributing of GCP and CP on images

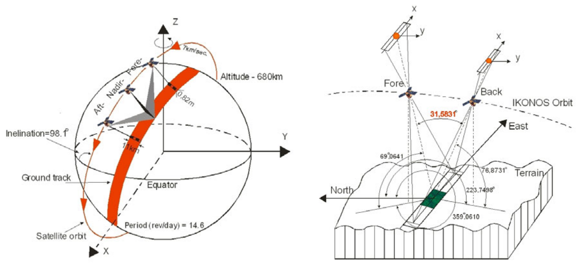
The selected areas are around 23.3km long by 12.4km with covering an area about 300sq. km in the north – west part of Krakow. Normal collection azimuth and normal elevation angle of satellite was used for calculating convergent angle (see Table 1 and figure 2). Overlapping was 97.3%.

2.2 Designing and measurement of the photogrammetrical points

In order to realize the process of 3D geopositioning, were processed of 31 photo points with an accuracy of about 10cm planimetric and 20cm vertical. The height of the ground points range from 244m to 429m. During the survey, the terrain point were documented with photographs, on which the terrain situation and survey position were visible.

	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 azimuth (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 Azimuth	157°.71	158°.11
Sun Angle Elevation	62°.13	62°.17
Convergence angle (δ)	31°.59	

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



a) b)

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

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 photo points identification on the imagery was definitely below one pixel.

2.3 Experiment

2.3.1 Generation of DSM with a use of software PCI Geomatica: Software PCI Geomatica produced by Canadian manufacturer is a combination of highly advanced tools dedicated to cartography, photogrammetry, Remote Sensing and GIS. This program is composed of separately purchased modules. A module that is responsible for ortho-adjustment process and generation of DSM is the OrthoEngine module. For the needs of this experiment, one applied the program PCI Geomatica in its version 10.03.R6.

2.3.1.1 Results and observations: Table 2 and figure 3 present the results of generation of DSM from Ikonos images for test field „Krakow" obtained in environment PCI Geomatica.

	No. of GCPs						
	1	2	3	5	10	15	18
RMS Error	**3.3**	**3.2**	**3.1**	**2.8**	**2.7**	**2.4**	**2.4**
Average Error	2.5	2.4	2.2	1.7	2.0	1.3	1.4
Maximum Error	8.2	7.9	7.5	7.2	5.1	4.6	4.6

Table 2. Report from program PCI

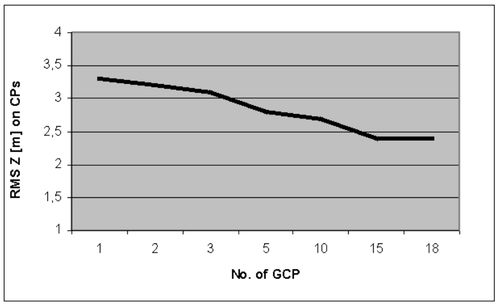


Figure 3. Altitude accuracy (on control points) for generation of DSM depending on a number of GCP in environment PCI Geomatica

For DSM generated in the program PCI a file with error report is attached. However, in the used program in version 10.02 the report file was empty. Thanks to direct contact with PCI company we obtained a patch (a fix), which eliminated lack of results in report file. The problem of lack of such report refers to this software in versions from 10.02 above. This problem has been fixed from version 10.03.R6.
Analysis of the obtained results enables for the conclusions that in order to obtain accuracy on the level of 3 m one should take advantage of 3 ground control points (GCP). Increase of a number of these points above 15 does not improve results.

2.3.2 Generation of DSM with a use of software ERDAS IMAGINE and LPS: ERDAS IMAGINE/LPS constitutes a sophisticated software packet for analysis and processing of spatial data. This packet serves first of all to elaborate, process and use satellite images, aerial photographs, radar images as well as GIS data. In this experiment, one used version 8.7 (the first one enabling for generation of DSM from IKONOS images was the version 8.6) and the recent version 9 known as Leica Photogrammetry Suit 9.0 (LPS). Module for ortho-adjustment of satellite images is in both versions the OrthoBase module.

2.3.2.1 Results and observations: Tables 3 and 4 as well as figures 3 present the results of generation of DSM from images Ikonos for test field „Krakow" obtained in environment ERDAS and LPS.

	No. of GCPs						
	1	2	3	5	10	15	18
Miniumim Error	-1.32	-1.55	-1.96	-2.09	-2.90	-3.13	-2.90
Maximum Error	6.77	6.02	5.53	5.52	4.70	3.50	3.48
Mean Error	3.16	2.49	2.03	2.00	1.06	0.81	1.02
Mean Absolute Error	3.35	2.81	2.67	2.44	2.09	2.00	1.98
RMS	**3.94**	**3.36**	**3.12**	**2.91**	**2.39**	**2.25**	**2.24**
Absolute Linear Error 90	5.93	5.10	4.65	4.55	3.73	3.31	3.28
NIMA Absolut Linear Error 90 ±	3.40	3.04	2.66	2.63	1.92	1.70	1.75

Table 3. Report from program ERDAS 8.7

	No. of GCPs						
	1	2	3	5	10	15	18
Miniumim Error	-1.36	-2.14	-2.69	-2.55	-3.50	-3.21	-2.95
Maximum Error	6.81	6.02	5.31	5.60	4.47	4.11	4.06
Mean Error	3.13	2.36	2.08	1.98	1.14	1.00	0.63
Mean Absolute Error	3.28	2.76	2.63	2.59	2.28	1.96	1.80
RMS	**3.83**	**3.27**	**3.07**	**3.02**	**2.54**	**2.21**	**2.08**
Absolute Linear Error 90	6.17	5.38	4.69	4.92	4.46	3.25	3.11
NIMA Absolut Linear Error 90 ±	3.26	2.87	2.59	2.58	1.85	1.74	1.70

Table 4. Report from program LPS 9.0

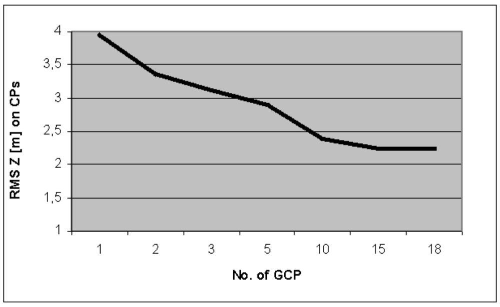


Figure 4. Altitude accuracy (on control points - CPs) for generation of DSM depending on a number of GCP in environment ERDAS 8.7

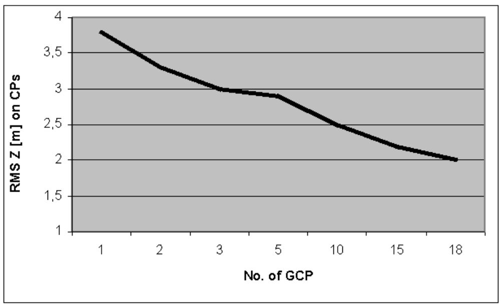


Figure 4. Altitude accuracy (on control points - CPs) for generation of DSM depending on a number of GCP in environment LPS 9.0

A file with error report is attached to generated DSM. This report is more accurate and detailed as compared with the report generated by the program PCI Geomatica. Programs ERDAS and LPS provide "on the fly" quasi-epipolar image generation, what considerably shortens the time needed for generation of DSM. Application of this attitude to generate DSM by the programs ERDAS and LPS is the fastest among the software packets tested.
Accuracies achieved with a use of the programs ERDAS and LPS are on the similar level. The recent version of LPS has shown minimum improvement of the achieved accuracies.

2.3.3 Generation of DSM with a use of software PHOTOMOD: Program Photomod is the product manufactured by Russian company Racurs. This program has been designed as the software for digital photogrammetrical station. But along with increased usage of the satellite images, this program used to evolve and nowadays it enables for work with the satellite images. In this experiment one used program Photomod in its version 4.1.479.

2.3.3.1 Results and observations: Table 5 and figure 5 present the results from generation of DSM from images Ikonos for the test field „Krakow" obtained in environment Photomod.

	No. of GCPs			
	1	2	5	15
RMS Error	**4.02**	**3.07**	**3.05**	**1.97**
Mean Absolute Error	3.84	2.58	2.57	2.42
Maximum Error	8.38	-7.89	-7.66	-7.58

Table 5. Report from program Photomod

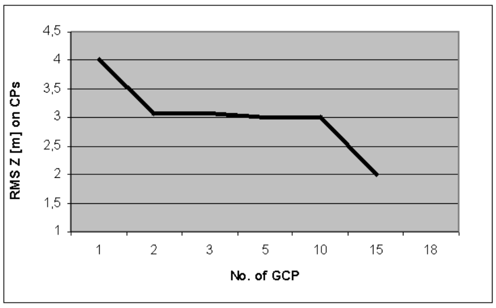


Figure 5. Altitude accuracy (on control points) for generation of DSM depending on a number of GCP in environment Photomod

Handling of the program Photomod is not as intuitive as handling the programs PCI and LPS. We used a version of this program labeled with a number 4.1.479 which was not so mastered in terms of generation of DSM. Residual and incomplete results have been caused by the problems that occurred during the experiments conducted with a use of the program Photomod 4.1. The results produced should be considered very carefully. Accuracy reports generated by the program were unclear what may have influenced the calculated values of RMS Z. On the basis of control points deviations (CPs) provided for in the report, RMS Z was calculated "manually" with the use of program MS Excel. During these experiments we frequently contacted with the Support Department of company Racurs. Our critical comments and detected errors contributed to the development of this software. Eventually, in February 2007 a new version of program Photomod was released. It was labeled as 4.2. The great advantage of this recent version 4.2 (information of ad leaflets) is a precise accuracy report as well as improved and simplified method of altering the character of points used for the process of generation of DSM (from GCP to CPs etc.).

2.4 Conclusions – (Ikonos)

Hereinbelow we present a cumulative results (figure 6) of accuracies obtained during the process of generation of DSM from satellite images IKONOS with a use of 4 commercial programs.

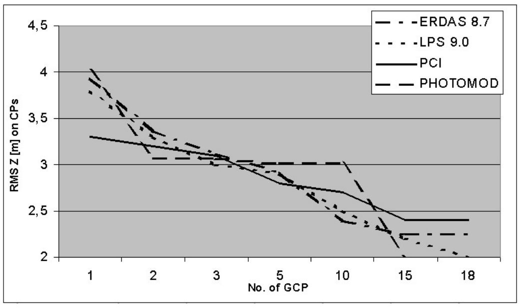


Figure 6. Cumulative diagram of comparative results for generation of DSM depending on a number of GCP with a use of programs ERDAS, LPS, PCI and Photomod

Accuracies achieved during the process of generation of DSM with a use of the said 4 programs are all on a very similar level. On these grounds we cannot clearly recommend, which program enables for achievement of the best results and accuracy.
Irrespective of the software, in the event of using 3 GCP per scene of IKONOS, one obtained an error RMS Z = 3m. Number of 15 photo-points enables for generation of DSM with the error RMS Z = 2m.
Software ERDAS and LPS utilize "on the fly" the quasi-epipolar image generation what considerably shortens the duration of DSM generation. Generation of images in normalized form took approximately 40 minutes (PCI). On the basis of that we may state that with similar accuracy results, programs LPS and ERDAS can generate DSM faster than software PCI.
Software PCI is characterized by a very high work stability.
Because of the fact that the date for marketing of the new release of Photomod 4.2 program was postponed from January to second part of February, it was not possible to test this new version of software.

3. TEST FIELD – RAWA MAZOWIECKA

3.1 Characteristics of the Cartosat – 1 system and images

In the framework of the long-term Indian program for monitoring of the surface of the Earth from space, which goes back to March 1988 when the satellite IRS-1A was placed on the orbit, the six subsequent satellite systems have been launched in turn: IRS-1C, IRS-P3, IRS-1D, OCEANSAT-1, TES and RESOURCESAT-1. They form one of the largest civil tele-detection constellations among the satellite systems. In May 2005 the next satellite system was situated on its orbit: CARTOSAT-1. The aim of this system is to acquire global stereoscope images in order to construct DSM or DTM.
This system is equipped with two high resolution scanners operating in panchromatic range, where the optical systems are positioned in fixed orientation. One camera is positioned +26 degrees while another -5 degrees in relation to the satellite orbit. This new approach enables for registration of the same fragment of land from the same orbit. In order to obtain images of the same area the satellite needs some 50 seconds to move along the orbit with a pace of 7.5 km/s, from its ceiling approximately 600 km. Unfortunately, due to different inclinations of various optical systems of the satellite the images are of uneven ground resolution what may be observed on images made forward and backward. The basic technical parameters characterizing satellite CARTOSAT-1 have been shown in Table 6 and Figure 7. One should take into consideration the following parameters of system CARTOSAT-1 when using the images of this type: base relation B/H is 0.6, time of imaging for the same type of ground, i.e. forward and backward is 53 s, the satellite has no TDI system.

Date on placement on the orbit	05 May 2005
Expected time of operation	7-9 years
Orbital pace	7.5 km/s
Number of circles around the Earth	14 during 24 h
One circle duration	93.5 min
Altitude	618 km
TELESCOPE Focal distance Angle of view	 1.98 m 2.4°
GSD: at inclination +26° - 5°	2.50 x 2.78 m. 2.22 x 2.23 m.
Width of imaging strip: For inclination +26° - 5°	 30.0 km 26.8 km
Number of pixels in line in scope of PAN	12 000
Time of crossing the equator by the satellite	10:30 a.m.
Revisiting frequency	Approximately 5 days
Radiometric resolution	10 bits
Inclination angle	97.8
Image Digital Format	GeoTIFF RPC

Table 6. Technical parameters of system Cartosat-1

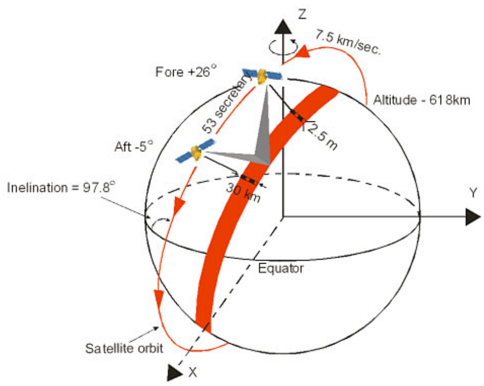
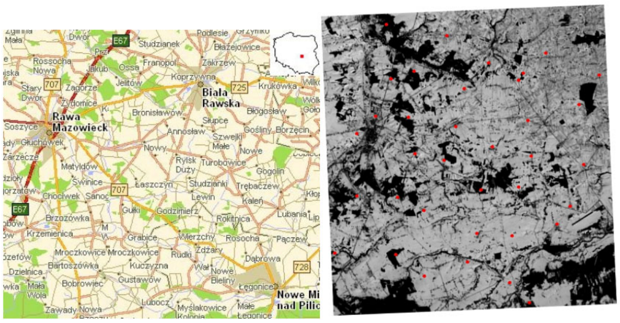


Figure 7. Elements of the orbit of system Cartosat-1.

The stereoscope scene delivered as of 25th February 2006 covers the area south-west of Warsaw – near Rawa Mazowiecka (figure 8). De-leveling on this area is 55 m.

3.2 Designing and measurement of the photogrammetrical points

When designing the photogrammetrical points, one tried to select such ground items that would enable for their identification on the image with a sub-pixel accuracy. This meant the measurement in a field with a method enabling for achievement of photo-points coordinates to obtain accuracy many times greater than pixel size.



a) b)

Figure 8. Topographic map covering test area – Rawa Mazowiecka, b) image from Cartosat-1 with the designed photo-points

This meant the measurement in a field with a method enabling for achievement of photo-points coordinates to obtain accuracy many times greater than pixel size. For this very purpose, one selected a measurement method with technology GPS FastStatic. This method enabled for achievement of coordinates of all the photo-points with the same, high accuracy, in relatively short period of time. Additional advantage of this method is the fact that it is not very much labor-consuming as far as obtainment of data with desired accuracy is concerned.
Additionally, in order to ensure a perfect identification of the points measured on the image, their selection was confirmed on a photo-draft and the photographs were taken with antenna digital camera on the tripoid and the photo-point itself. Documentation prepared in this way guaranteed precise measurement in the field and on the image. Placement of the measured photo-points has been presented on figure no. 8.

3.3 Experiment

3.3.1 Generation of DSM with a use of software PCI GEOMATICA: Utilization of images obtained from system Cartosat-1 in the software PCI Geomatica requires a purchase of additional module.

	No. of GCPs					
	5	7	10	15	18	22
RMS Z [m]	3.6	2.0	1.5	1.2	1.1	1.1
Min. [m]	1.5	1.5	1.3	0.5	0.5	0.4
Max.[m]	9.2	3.9	3.1	2.4	2.3	1.8

Table 7. Report from program PCI

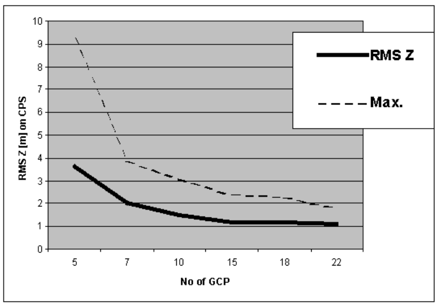


Figure 9. Altitude accuracy (on control points) for generation of DSM depending on a number of GCP with the use of polynomial method (RPF) in environment PCI

Results of this experiment enabled for definition of the optimized number of GCP, i.e. 9-10, offering accuracy on the level of 1.5 m (table 7 and figure 9).

3.3.2 Generation of DSM with a use of software LPS: In order to work with images from Cartosat, one has to install a patch (a fix), which was not offered with the standard version of this software when this article was written.

	LPS
RMS (Z) [m]	**1.71**
Min. [m]	0.06
Max.[m]	3.35

Table 8. Report from program LPS

The results obtained for the tested area can be characterized with relatively minor de-leveling (minimum altitude 137 m, and maximum 192 m.). They prove that having sufficient number of GCP, we may very well achieve the accuracy on the level of 1.5-1.7 m with a use of the program LPS (Table 8) (Dąbrowski et al., 2006).

3.4 Conclusions – (Cartosat-1)

System CARTOSAT-1 may constitute economically attractive source of data for generation of NMP of global range. The very basic observations from the conducted experiment are as follows:

- software LPS and PCI may be used for simple obtainment of NMP from the satellite system CARTOSAT–1,
- system CARTOSAT–1 requires relatively large number of ground control points, at least 9-10 in order to achieve safe result. Without the photo-points one managed to obtain accuracy in range 200-300 m, what proves low precision of coefficients RPC,
- the described experiment regarded the land of relatively minor de-leveling and consequently it has not enables for more precise answers on capacity of this new system in mountain areas,
- on the Web page www.Racurs.ru, maintained by the manufacturer of software Photomod, one may find a remark that version 4.2 of this program has an option to collaborate with images from Cartosat what in turn enables for generation of DSM from this very system.

4. FINAL CONCLUSIONS

Currently there are several optical systems available that enable for generation of DSM, among others Cartosat-1, SPOT 5 and the very high resolution systems, such as IKONOS, QuickBird, and OrbView.
This experiment proved that using the RPC coefficients provided for satellite images one may generate DSM of accuracy close to 2 m with the use of commercial software packets.
In January 2006, a system ALOS achieving stereoscope image, which operates similarly to Indian system Cartosat-1, was placed on the orbit. This fact evidences great interest in the satellite systems enabling for obtainment of three-dimensional Earth surface images.

We should also remember that in 2006 one launched four new systems of one meter accuracy, while in 2007 the system of accuracy 40 centimeters is to appear.
It seems well reasonable to continue the research regarding the capacities of the new satellite systems enabling for generation of DSM.
The very basic application of generated DSM may be the works on the areas where there are no DSM-like products of similar parameters, or where one observed rapid changes in land surface shape (natural disasters, or intensification of human-related activities).

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REFERENCES

Büyüksalih, G., Kocak, M.G., Oruc, M.*, Akcin, H., Jacobsen, K, 2003: Handling of IKONOS-images from Orientation up to DEM Generation, *Joint Workshop "High Resolution Mapping from Space 2003*", Hannover.

Dial, G., and Grodecki, J., 2003. IKONOS Stereo Accuracy with Ground Control. *ASPRS Annual Conference Proceedings*, Anchorage, Alaska.

Dąbrowski R., Fedorowicz-Jackowski W., Kędzierski M., Różycki S., Walczykowski P., Wolniewicz W., Zych J., printing in progress. Ocena dokładności generowania NMP z wykorzystanie Cartosat-1. *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, Tom 16.

Kaczynski. R., Majde. A., Ewiak . I., 2004. Accuracy of DEM and Ortho Generated from IKONOS Stereo Images. *20th ISPRS Congress*, Istanbul, Turkey, 2004

Rozycki S., Wolniewicz W., 2007. Accuracy assessment of DSM extracted from IKONOS stereo images. *New Developments and Challenges in Remote Sensing*. Millpress, Roterdam, ISBN 978-90-5966-053-3, pp. 667- 673.

Toutin, T., 2002., Error Tracking in IKONOS Geometric Processing Using a 3D Parametric Model. *Photogrammetric Engineering and Remote Sensing*, Vol.68 (11).