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POTENTIAL FOR RESURS DK-1 SATELLITE DATA

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Abstract. The results of the research project funded by the Polish Ministry of Science and Higher Education are presented. The main aim of the project was an assessment of new Russian satellite data for orthophoto generation. The methodology of the geometrical correction and orthorectification of raw Resurs DK-1 panchromatic images on the basis of metadata analysis with accuracy acceptable for mapping in the scale of 1:10,000 was elaborated and presented. The algorithm of the geometrical correction of Resurs DK-1 image data was elaborated based on the adopted modules valid for IKONOS data which is implemented in the Ortho Engine PCI Geomatica software. Two geometric correction methods have been tested. In each method, the measurements of the image coordinates of Ground Control Points (GCP's) and Independent Check Points (ICP's) along with the use of semi-automatic methods implemented in the Ortho Engine software were performed. A Digital Elevation Model (DEM) with accuracy better than 4m is required.

Keywords: satellite data, panchromatic image, Ground Control Point.

1. Russian satellite Resurs DK-1 system

Resurs DK-1 was designed by RASA (Russian Aviation Space Agency) in the frame of the National Space Programme of the Russian Federation (Anshakov and Skirmunt 2000). The main designer and producer of the satellite system Resurs DK-1 is State Research and Production Space Rocket Centre "TsSKB-Progress" (Fournier-Sicre *et al.* 2003). Resurs DK-1 with a Geoton RDK-1 camera was placed on the elliptical orbit with an inclination of 63° with an apogee and perigee of 585 km and 355 km respectively on June 15th, 2006 by the spacecraft Soyuz-U. The revisit time of this satellite is 6 days.

The acquisition of image data by Resurs DK-1 sensors is realized in panchromatic mode P (0.58–0.8 µm) and multispectral mode (M) in three bands: M1 (0.5–0.6 µm), M2 (0.6–0.7 µm) and M3 (0.7-0.8 µm) with a spectral resolution of 10 bit/pixel and with 1 m GSD for P and 2-3 m for M in swath width from 4.7 km to 28.3 km for the nominal scanning range of 450 km.

2. Description of the test data

Two panchromatic images with GSD about 1 m were tested. The first image covering 12 by 12 km is representing the centre of Warsaw. This image was taken on September 24th, 2006 using the Geoton RDK-1 camera with an inclination of 6.35° and a scan azimuth angle of 31.45°. The second one covering about 10 by 10 km of the North-West of Cracow was acquired on July 3rd, 2006. Sensor inclination of-nadir was 7.65° and a scan azimuth angle made about 30.76°. In both cases, the scenes were acquired with sun elevation of 37°.

3. Geometrical correction of Resurs DK-1 images

The methodology of the geometrical correction of Resurs DK-1 satellite images elaborated by the authors uses an adapted model of geometric reconstruction for IKONOS. However, in the case of new Russian satellite images, the main problem is the unavailability of the users to employ special "Z-Space" software used in Russia for the orientation of Resurs DK-1 data. Only files representing orbital parameters for each image and a set of not well defined coefficients have been available to the authors. These parameters have been used for elaborating algorithms for a geometric reconstruction of Resurs DK-1 images using Ortho Engine modules applied normally for the orientation of IKONOS data only.

The proprieties of the internal programming environment of the PCI Geomatica software have been used. The adaptation of the recorded structure of Resurs DK-1 metadata to the structure of RPC coefficients format and the structure of the orbital parameters of IKONOS system was the main task of the processed algorithms. The first algorithm relates to the geometric reconstruction of Resurs DK-1 images based on the rigorous mathematical model while the second one is based on the rational function model.

For two images of Resurs DK-1 from 24 to 28, well identified natural GCP's were measured applying GPS technique. The measurement of the image coordinates of the points was performed using the modules of Ortho Engine PCI Geomatica software v.10.3. The accuracy of the measurement and the identification of GCP's and ICP's should be better than 0.4 m in X, Y and 0.3 m in height. The examples of GCP's and ICP's are shown in Fig. 1.

Two mathematical modelling methods of the geometric reconstruction of Resurs DK-1 images have been used. The analysis of the influence of the number and the distribution of control points on each scene on the result of geometric reconstruction was realized in each method. The first method is the collinearity based mathematical model which describes the rigorous geometry of the scanner utilizing knowledge of satellite trajectory and sensor calibration data. This method integrates all components of viewing geometry and sensor as well as the Earth's parameters and cartographic projection. In this method, 5 to 12 well identified and distributed GCP's were measured. Accuracy has been checked with well defined ICP's (Table 1).

The model of geometric correction based on the first method is equivalent to the accuracy of about a half pixel of the source image. RMSE X = 0.45 m and RMSE Y = 0.46 m have been achieved on 16 ICP's. Using the orbital parameters of Resurs DK-1 satellite caused the limitation of measured GCP's required for geometric reconstruction. The results obtained in this method show the influence of real orbital satellite parameters on the mathematical model of the geometric reconstruction of Resurs DK-1 images. The result below one pixel of the source image is possible to be achieved when only 5 GCP's are used. If the number of GCP's is increased to 8, better results are achieved employing this method (see Table 1).

In the second method based on the rational function mathematical model of the geometric reconstruction of Resurs-DK-1 images, the unknown of the terrain related to Rational Polynomial Coefficients (RPC) were calculated on the basis of GCP's measured in the field and image. The correlation of the unknown RPC parameters depends on the number of GCP's, the accuracy of their identification in the field and image and their distribution on the image. RPC data have been estimated independently from a different number of control points. The results of geometric reconstruction are shown in Table 2.

The optimal degree of the polynomial for the estimation of the relationship between image and ground coordinates has been investigated. Using 18 GCP's allows calculating 9 polynomial coefficients. Increasing the number of control points up to 24 needed for a better determination of RPC gives the result of geometric correction RMSE X = 0.32 m and RMSE Y = 0.36 m. However, in this case, the necessity of measuring only 8 GCP's disqualifies the method of a terrain related RPC-solution.

Fig. 1. An example of GCP's on Resurs DK-1 images

Table 1. The results of the geometric reconstruction of Resurs DK-1 images applying the 1st method

Number of GCP's for test areas Warsaw/Cracow	Number of ICP's for test areas Warsaw/Cracow	RMSE at the ICP's [meters]			
		Warsaw test area		Cracow test area	
		X	**Y**	**X**	**Y**
12	16/12	0.44	0.46	0.44	0.46
10	18/14	0.45	0.47	0.46	0.44
8	**20/16**	**0.46**	**0.48**	**0.45**	**0.46**
6	22/18	0.53	0.48	0.57	0.53
5	23/19	0.73	0.82	0.84	0.92

Table 2. The results of the geometric reconstruction of Resurs DK-1 images applying the 2nd method

Number of GCP's	Number of ICP's for test areas Warsaw/ Cracow	Number of polynomial coefficients	RMSE at the ICP's [meters]			
			Warsaw test area		Cracow test area	
			X	**Y**	**X**	**Y**
24	4/0	**12**	**0.32**	**0.36**	0.37	0.36
22	6/2	11	0.34	0.32	0.36	0.38
20	8/4	10	0.40	0.38	0.39	0.38
18	**10/6**	**9**	0.45	0.45	0.41	0.44
16	12/8	8	0.52	0.46	0.48	0.45
14	14/10	7	0.58	0.62	0.49	0.55
12	16/12	6	0.76	0.82	0.69	0.71
10	**18/14**	**5**	**0.82**	**0.90**	**0.88**	**0.97**
8	20/16	4	1.04	1.18	1.22	1.34

Accuracy below one pixel is guaranteed only if 10 control points evenly distributed in the scene are used.

Taking into account an economical aspect of geometrical reconstruction to reduce expensive field measurements of GCP's, it is recommended to use the first method. However, the final choice depends on an access to original orbital sensor data which is usually not the case. Additionally, when analyzing a' priori and a' posteriori errors at the ICP's, it was confirmed that this method was the most credible in the sense of correct results.

The geometrical reconstruction of Resurs DK-1 source images with the use of the method based on the independent determination of polynomial coefficients is well-founded. It was confirmed that to obtain similar RMSE at check points in the analyzed methods, 18 control points in the method based on RPC determination was required. This method could be used as an alternative in the case if access to the full metadata of the Resurs DK-1 image is impossible. DK-1 satellite data can be geometrically corrected up to a half pixel of the source image.

4. Requirements for the orthorectification process of Resurs DK-1 images

The influence of terrain height variation on the accuracy of orthoimages generated from the nadir satellite image is not that big as in case of aerial photographs in the small scale. Therefore, for the orthorectification of satellite images taken with small of-nadir viewing is possible to use DEM with less accuracy (Ewiak and Kaczynski 2005). The accuracy of digital orthoimages depends on the accuracy of the geometrical correction of source Resurs DK-1 images and the accuracy of DEM.

For the purpose of generating orthoimage with the accuracy of a topographic map in the scale of 1:10,000, DEM from SRTM could be used. The following steps are needed to perform:

- geometrical correction using sensor orbital data, measuring a minimum of 5 ground control points and using DEM with accuracy better than 12 m for images acquired with a small of-nadir angle,
- geometrical correction of the source image with the determination of a minimum of 4 polynomial coefficients and the use of DEM with accuracy better than 6 m.

The influence of terrain height variations on the orthoimage of test areas is small. Therefore, Shuttle Radar Topographic Mission (SRTM) data have been analyzed. On the basis of a statistical analysis of SRTM data realized in the Institute of Geodesy and Cartography in Warsaw, it was confirmed that in the 90% area of Poland, the accuracy of height was about 2.9 m for flat and 5.4 m for hilly terrain (Karwel and Ewiak 2008). However, it has been found that SRTM data contains a systematic error component in height (Jacobsen 2006; Ewiak and Kaczynski 2008). After the elimination of component DEM, SRTM have been used for generating orthoimages from Resurs DK-1 images with the planimetric accuracy of 2.5 m required for the scale of 1:10,000.

5. Estimation of the accuracy of the orthorectification process of Resurs DK-1 source images

The accuracy of orthoimages has been achieved on the basis of differences calculated from coordinates on orthoimages and measuring reference ground position in the field. Accuracy achieved employing the above introduced methods was calculated on 18 ICP's for Cracow test area and 23 for Warsaw test area. In the orthorectification process, the corrected SRTM data set with the accuracy of ±1.1 m for Cracow test area and ±0.8 m for Warsaw test area were used (Karwel and Ewiak 2008). The results of the orthoimages generated with 1m pixel size are shown in Table 3. For all used orientation methods, the obtained orthoimage accuracy corresponds to the required accuracy of the base map in the scale of 1:10,000. The accuracy of orientation based on the rigorous mathematical model of the satellite sensor of Resurs DK-1 corresponds to the accuracy of the base map in the scale of 1:5,000. It has been found that the accuracy of orthoimages generated with 50cm pixel size is only imperceptibly higher.

Table 3. The accuracy of the geometric correction of Resurs DK-1 images

Characteristic of geometrical reconstruction methods of Resurs DK-1 images	RMSE XY [m]	
	Warsaw test area	Cracow test area
QUALITY ASPECT		
Rigorous model with 8 GCPs	0.62	0.61
Polynomial coefficients calculated on the basis of 24 GCPs	0.56	0.61
ECONOMICAL ASPECT (if less GCPs are used)		
Rigorous model with measured of 5 GCPs	1.12	1.23
Polynomial coefficients calculated on the basis of 12 GCPs	1.66	1.87

The best quality of the orthorectification process of Resurs DK-1 images requires a large number of GCP's for the calculation of RPC coefficients. The economical aspect of the geometric reconstruction of Resurs DK-1 scenes showed the necessity of using the original polynomial coefficients provided by the satellite imagery vendor and computed from the rigorous sensor model.

6. Comparision of handling Resurs DK-1 and IKONOS-2 data

The analysis was related to the technical and economic aspects of the generation of digital orthoimages with accuracy required for maps in the scale of 1:10,000. The orthoimages have been generated based on images for the test areas:

- a panchromatic image of IKONOS and that of Resurs DK-1 covering the first test area (121 square kilometres) situated in the centre of Warsaw with flat terrain,
- a panchromatic image of Resurs DK-1 covering the second test area (100 square kilometres) situated in the North - West part of Cracow with hilly terrain.

Better results of the panchromatic scene of IKONOS have been achieved due to the higher precision of RPC supplied by GeoEye and higher internal accuracy of the pixels in the IKONOS image (Kaczynski and Ewiak 2005). The accuracy of geometrical correction in all methods of Resurs DK-1 images met the standards for topographic maps in 1:10,000 and smaller scales. A sample of orthoimages is shown in Fig. 2.

The small off-nadir viewing angles of the sensor have caused that the geometric dislocation of the orthoimages are mainly affected by the scene orientation of the source image data. DEM with accuracy about 4 m is sufficient for the orthorectification images taken with small of-nadir collection for IKONOS and Resurs DK-1. The source of such DEM to be used for both types of images could be a corrected set of SRTM data.

The reason of applying the given type of satellite image can be only the cost of the source satellite scene. The price of the programmed scene of Resurs DK-1 for one square kilometre is 9.5 EUR for a panchromatic image. The price of the archive scenes of Resurs DK-1 is reduced to 8 EUR. The Geoinformation Agency "Innoter" from Moscow is the main distributor of Resurs-DK-1 image data.

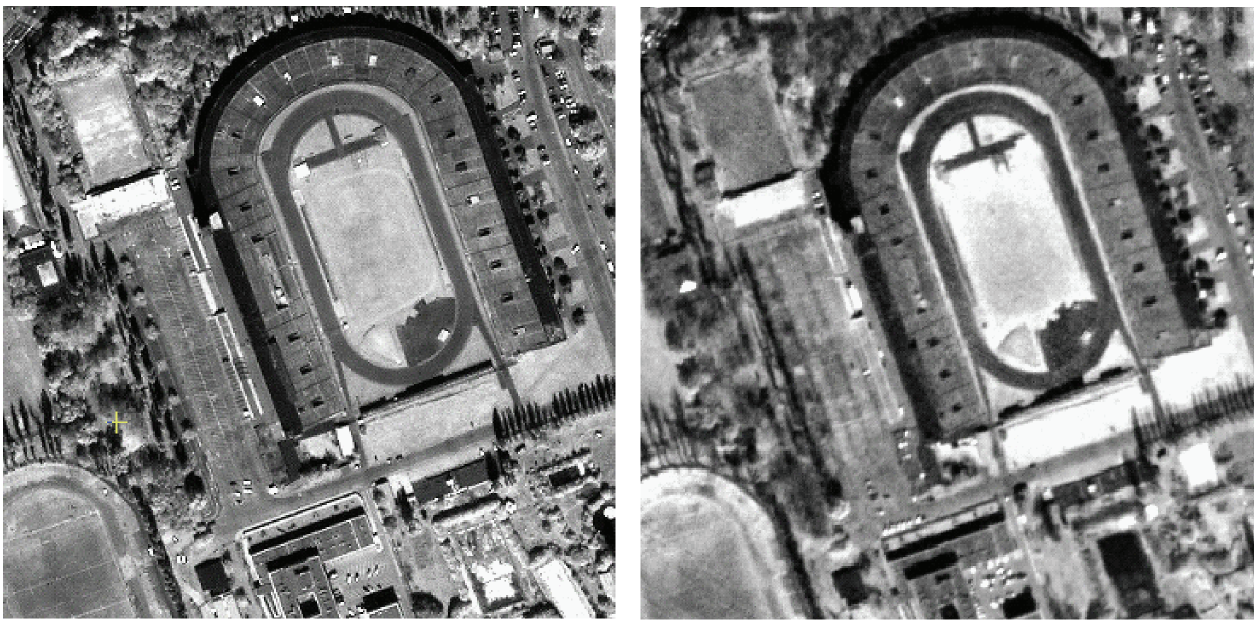

Fig. 2. A part of the orthoimages of Warsaw test area (IKONOS – on the left, Resurs DK-1 – on the right)

The price of one square kilometre of the IKONOS panchromatic image is about 18 EUR Resurs DK-1 images, if would be easy available to the users, could be used for mapping and updating topographic maps up to the scale of 1:10,000.

7. Conclusions

The high resolution Russian satellite images of Resurs DK-1 could be used for generating orthoimages in the scale of 1:10,000. The accuracy of geometric reconstruction depends on the method used taking into account the rigorous mathematical sensor model and terrain related RPC coefficients as well as the number and distribution of well identified GCP's.

The transformation of the image to the ground coordinate system can be performed with accuracy better than half a pixel for Resurs DK-1 image and IKONOS satellite systems. Geometric accuracy for Resurs DK-1 images is about 0.5 m. The accuracy of DEM required for orthorectification depends on the of-nadir acquisition of raw images.

DEM with the accuracy of the height of about ±4 m could be used for the rectification process of Resurs DK-1 with a small of-nadir angle and flat area. Orthoimages can be generated from DK-1 and IKONOS with accuracy corresponding to the geometric standards in Polish maps in the scale of 1:5,000 but the information contents of these images refer to the scale of 1:10,000.

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