

ACCURACY OF DTM GENERATED FROM SPOT 4 AND SPOT 5 HRS DATA

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ABSTRACT:

SPOT 4 stereo data from two different orbits with B/H 0.83 of the area in South-East Poland with denivelations reaching 550 m was elaborated in IGiK. 12 GCP's and 15 ICP's taken from 1: 10 000 topographic maps and orbital data have been used for orientation with the use of Image Station Multisensor Triangulation SPOT. The accuracy achieved on GCP's: RMS X = 2.2 m, RMS Y = 2.3 m, RMS Z = 1.1 m; and on independent check points (ICP's) RMS X = 5.0 m, RMS Y = 2.9 m, RMS Z = 4.7 m. DTM has been generated automatically with the use of MATCH-T Inpho software and filtered with in-house software. DTM prepared on the basis of SPOT stereo data has been checked against reference data - DTM generated from aerial photographs in scale 1:26 000.

The accuracy of DTM generated with SPOT 5 HRS within the HRS Scientific Assessment program (HRS-SAP) of ISPRS and CNES on site 9 Chiemsee (Germany) is also presented. Geomatica OrthoEngine of PCI has been used for orientation and DTM generation.

1. TEST DATA

1.1 HRV SPOT 4

The two SPOT-4 panchromatic images level 1A over South-East Poland were acquired on 5 September and 12 September 1987 and recorded by Spot Image France with significant radiometric differences between the two images, particularly in agricultural areas. The inclination of the sensors optical axis was 24.8° R and 18.5° L respectively. The base-height (B/H) ratio of the model was approximately 0.85, which promised good resection. The elevation range of the terrain was from 50 m - 550 m. Modern topographic maps in the scale 1:10 000 cover the test area. From these maps, 43 well-defined control points and 15 check points have been captured using a digitizing table with accuracy better than 3 meters in the X, Y and under 1 meter in Z. Four-times enlargements were used, making it possible to mark them within 1/4 of a pixel.

Two test areas have been selected within borders of stereoscopic SPOT 4 scene. Two sequential aerial photograph models at a scale of 1:26 000 marked range of every of these areas. For first test area representing mountainous and hilly terrain 6 control points were measured in field by GPS methods. Aerotriangulation was carried out in order to calculate ground coordinates for additional 15 control points with standard deviations $\sigma_X=0.3m$, $\sigma_Y=0.3m$, $\sigma_Z=0.2m$. These points, along with GPS points have been used as full set of control points for the first test area. For second test area representing hilly and flat terrain, 8 control points were measured in field by GPS methods. Similarly as for the first test area, 21 control points were estimated with statistical accuracy $\sigma_X=0.2m$, $\sigma_Y=0.1m$, $\sigma_Z=0.2m$. This set of points was used as full set of control points for second test area.

1.2 HRS SPOT 5

The following data has been used:

- 8 bit SPOT 5 HRS image data - four scenes level 1A - (size 12000 x 12000 pixels = 120 km x 60 km) of the Bavarian test area from two viewing directions in TIFF format with metadata in DIMAP format. The image data has been acquired on October 1st 2002 with a sun elevation of 38 degrees and nearly no clouds, which promises sufficient image matching possibilities. HRS sensor on SPOT 5 produces image stereo pairs with two optical sensors looking forward and backward with ± 20 degrees with respect to nadir. It has a spatial resolution of 10 meters across track and 5m ground sampling distance along track for obtaining higher accuracy of the parallaxes for the DTM generation. The swath of the HRS is 120 km (12000 CCD elements) and one acquisition sequence is 600 km along track;

- XML-files containing all additional information regarding time synchronization, position (DORIS), attitude (star sensors) and inner orientation;

- ASCII text files containing information on the delivered data;

- 81 ground control points (fixed points), with detailed description of the exact location of each point, with planimetric and height accuracy in terms of the RMSE values for each of the GCP's were better than $\pm 1m$;

- Interactive topographic map "Bayern 3D" in scale 1: 25 000 for locating ground control points in the HRS data.

This data has been delivered by CNES for realization of the program HRS-SAP.

2. THE METODOLOGY OF GEOMETRIC CORRECTION OF PANCHROMATIC STEREO HRV SPOT 4 DATA

2.1 Specification of methodology

In order to determine the factors influencing the result of orientation of stereoscopic scene HRV SPOT 4, the series of methodical research work was performed. The following factors were considered:

- Filtration of raw SPOT 4 data in spectral and frequency domain;
- Accuracy of measurement and identification of control points and check points;
- Accuracy of measurement of image coordinates;
- Accuracy of delimitation of satellite orbital parameters;
- Distribution of ground control points.

The specific of measurements the each of photogrammetric point on stereo images SPOT 4 (the semi-automatic correlation method) did not require the detailed analysis of influence of radiometric quality of these images on accuracy of relative and absolute orientations. However, the ability of identification of control points and check points was examined on original scenes and on the images after radiometric corrections.

The accuracy of control points depends on accuracy of their measurement in field as well as on accuracy of identification on SPOT 4 images.

The image coordinates of control points, check points and tie points were measured by correlation methods using TRIFID software installed on the SSK Pro workstation, under the Intergraph photogrammetric environment (Image Station Multisensor Triangulation - SPOT).

The analysis of results of bundle adjustment shows that the range of estimated accuracy of photogrammetric adjustment is good when the standard deviation of adjustment does not change. The choice of accuracy of measurement outside of this range worsens the credibility of estimation of adjustment. For the tested panchromatic stereo SPOT 4 scene the accuracy of photogrammetric measurement was accepted with range from 4 μ m to 6 μ m.

If GCP's are symmetrically distributed then twelve points are sufficient for orientation of stereoscopic SPOT 4 scene.

The influence of accuracy of delimitation of satellite orbital parameters on absolute orientation results has been examined for established construction of bundle and determined number and distribution of control points as well as tie points on stereoscopic SPOT 4 scene. This accuracy is characterized by standard deviation. It has been confirmed that the results of adjustment being the function of these standard deviations do not change significantly; therefore the approximate values of sensor parameters for orientation of stereoscopic scene HRV SPOT 4 were used.

2.2 Results of geometric corrections

The results of geometric correction of panchromatic stereoscopic scene HRV SPOT 4 for above-mentioned analyses were received, in reference to full scene and to the separated fragments. Results are shown in Table 1.

In orientation process, except the approximate parameters of orbit, the control points measured on topographical map in scale 1:10,000 permits for orientation the panchromatic stereoscopic scene of HRV SPOT 4 with accuracy below half pixel. The use of control points measured in field by the GPS techniques or appointed in space triangulation process on the basis of aerial photographs in scale 1:26,000 permits to increase the orientation accuracy to 1/3 of pixel.

3. THE ACCURACY OF GEOMETRIC CORRECTION OF BLOCK SCENES HRS SPOT 5

Each scene has been oriented independently using from 15 to 36 ground control points. Table 2 shows the numbers of ground control points and checkpoints on rectified scenes. Many natural GCP's have not been well identified. The planimetric accuracy of control points and checkpoints is about 1m. There is also an identification error that can reach up to 1m. For good B/H ratio $RMS_z=1.5m$.

Results of orientation with the use of Toutin model (PCI Geomatica v. 9.1 software) and ground control points are shown in Table 3. The accuracy of orientation of block panchromatic scenes HRS SPOT 5 is 2m in planimetry and 2m in height independently form terrain type.

Range of elaboration	Number of control points	Number of check points	RMSE in meters on the:					
			Control points			Check points		
			X	Y	Z	X	Y	Z
Full scene	12	15	± 2.2	± 2.3	± 1.1	± 5.0	± 2.9	± 4.7
First test region	14	7	± 2.1	± 1.7	± 1.2	± 4.4	± 3.3	± 3.4
Second test region	16	13	± 1.6	± 1.5	± 0.9	± 3.0	± 3.0	± 3.1

Table 1. The accuracy of orientation of stereoscopic scene SPOT 4

Scene No.	01 (5 062-252/1 1S)	02 (5 062-252/1 2S)	03 (5 062-253 1S)	04 (5 062-253 2S)
Ground Control Points	15	15	36	36
Check Points	5	5	16	16

Table 2. Numbers of GCP's and checkpoints used for orientation of the scenes

Scene No.	RMS Errors on the Control Points [m]			RMS Errors on the Check Points [m]	
	X	Y	Z	X	Y
01	± 1.8	± 2.8		± 3.2	± 2.6
02	± 1.9	± 2.5		± 1.1	± 3.2
03	± 1.9	± 2.0		± 1.9	± 1.8
04	± 2.4	± 1.8		± 2.1	± 2.2
All Scenes	± 1.6	± 1.9	± 2.1		

Table 3. RMSE of the orientation results of block scenes HRS SPOT 5

4. THE METHODOLOGY OF DTM GENERATION ON THE BASIS OF PANCHROMATIC HRV SPOT 4 DATA

4.1 Specification of methodology

The methodology of measurement of DTM on the panchromatic images HRV SPOT 4 was elaborated. The modules of photogrammetric software's like MATCH - T Inpho and Image Station Automatic Elevation Collection (ISAE) Z/I Imaging were used for measurements of grid of elevation points with rows and columns spaced dependent from terrain type.

The basic factors influencing the results of correlation measurement of DTM are described in Ph.D. thesis of Mr. Ewiak. The most important factors are:

- Radiometric accuracy of SPOT 4 images;
- Accuracy of delimitation of Rational Function Coefficients for stereoscopic SPOT 4 Pan scene;
- Method of correlation;
- Parameters of the software used for auto-correlation measurement of height-points.

Close correlation was found between accuracy of DTM and the radiometric accuracy of SPOT 4 images. In order to assure maximum effectiveness of correlation measurement, the optimum radiometric processing has been done on the raw panchromatic SPOT 4 scenes.

It has been also found that the accuracy of delimitation of Rational Function Coefficients, responsible for the correctness of exterior orientation parameters of SPOT 4 scenes, influences fundamentally the accuracy of measurement of DTM.

It show also, that the incompetent usage the added parameters of software realizing the correlation measurement of the DTM can demote the accuracy of height measurements.

The problem of limitations of MATCH - T as well as the ISAE was solved. This problem concerned the admissible size of measuring grid of DTM for stereoscopic SPOT 4 images.

4.2 The results of measurement of DTM

The measurements of DTM were performed on the separated fragments ("Region I" and "Region II") of stereoscopic scene SPOT 4. The rational function coefficients were calculated in independent process.

For the "Region I" the grid of height-points was generated with spacing 25m and for "Region II" with spacing of 100m. The accuracy of measured DTM were examined on the basis of their comparison with reference DTM, which were obtained by auto-correlation methods from aerial photographs in scale 1:26 000, with manual edition.

The accuracy of reference DTM was estimated as $RMS Z = \pm 0.5m$. The results of analyses of accuracy for each DTM, taking into account the influence of the factors described above is shown in table 4.

The use of elaborated methodology, permitted to measure DTM with accuracy $RMS Z = \pm 4.7 m$ for mountainous and hilly terrain and $RMS Z = \pm 2.6 m$ for flat terrain.

Additionally, Mr. Ewiak has elaborated software for filtration of wrong DTM points and their removal, as well as the interpolation of new points on the basis of the analysis of neighboring terrain. The software is written in programming language Borland Delphi 6.0 for the operating systems Windows NT, 2000, XP. **Using this software the accuracy of DTM was increased to $RMS Z = \pm 3.9 m$ for mountainous and hilly terrain and to $RMS Z = \pm 1.8 m$ for flat terrain.**

The factors influencing accuracy of correlation measurement of DTM	RMS on height points of DTM for different test regions [m]	
	Region I	Region II
Raw images of SPOT 4	± 8.8	± 4.5
Radiometric accuracy of images	± 8.4	± 4.1
Accuracy of delimitation of Rational Function Coefficient	± 7.6	± 3.4
Selection of software parameters	± 6.8	± 2.6
The grid size of DTM	± 4.7	± 2.6

Table 4. The influence of basic factors on results of measurement of DTM by correlation method of the HRV SPOT 4

Test region DLR-DTM	Percentage of pixels with accuracy better than				Percent of bad correlation	Remarks
	1m	2m	5m	10m		
01	17.0	16.1	30.8	15.2	20.8	
02	20.1	17.2	25.9	14.1	22.7	
03	20.9	18.0	30.7	15.9	14.4	
04	19.7	16.7	27.4	13.6	22.6	
05-1	4.9	4.6	10.2	14.3	66.0	very bad correlation
05-2	8.0	7.1	16.1	13.8	55.0	very bad correlation
06	14.9	14.1	31.7	21.1	18.2	

Table 5. Accuracy of DTM for the test regions (raw DTM 20m pixel size interpolated to reference DTM)

Accuracy of DTM	Test region (DLR-DTM)						
	01	02	03	04	05_1	05_2	06
RMSE	± 2.6	± 1.8	± 2.4	± 2.5	± 14.2	± 6.7	± 2.8

Table 6. The RMSE of DTM generated for different test regions from HRS SPOT 5

5. THE ACCURACY OF DTM GENERATED ON THE BASIS OF PANCHROMATIC HRS SPOT 5 STEREO IMAGES

Epipolar images and OV's have been generated for two stereo images: 01-02 and 03-04. PCI Ortho Engine has been used for matching and DTM generation. Matching and DTM generation have been performed for both stereo scenes with pixel 20m as 16-bit image data in GeoTiff format. DTM have been extracted only for the 7 test regions. Next, the DTM have been interpolated to the pixel size as given in reference DTM data. Generated DTM has neither been verified in order to eliminate gross errors nor edited. The result of comparison tests is shown in table 5.

For five of the test regions 60% of results of DTM is in the range from 1m to 5m. The detailed analyses of histograms of images representing DTM and results are shown in table 6.

6. CONCLUSION

The use of well-elaborated methodology of correlation measurement on the panchromatic HRV SPOT 4 images permits to achieve DTM with the accuracy similar to the accuracy of raw DTM generated on the basis of the panchromatic HRS SPOT 5 images. SPOT 4 Pan stereo data can be used for generation of contour lines with 20 m interval and orthophotomaps in scale 1:25 000. Technology for generation of DTM for orthophotomaps in scale 1:25 000 from HRV SPOT 4 Pan stereo data can be used for mapping and up-dating topographic maps in Africa and in Europe including Poland. This technology can be also adopted for new satellite data like IKONOS and QuickBird stereo data.

To increase the accuracy of raw DTM generated on the basis of the panchromatic HRS SPOT 5 images the use of suitable editing and filtering techniques as well as additional supplementary measurements (breaklines, etc.), especially for mountainous and hilly terrain is recommended.

The use of proper methodology for correlation measurement on the basis of the panchromatic HRS SPOT 5 and for HRV SPOT 4 stereo images will permit to generate DTM with accuracy in elevation better than 2m.

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