

COMPARISON OF DIGITAL ELEVATION MODELS GENERATED FROM SPOT-5 HRS STEREO DATA AND CARTOSAT-1 STEREO DATA

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ABSTRACT:

SPOT-5 and Cartosat-1 are mapping satellites with high resolution and along-track stereo capability. This paper describes the work carried out towards the qualitative and quantitative comparison of the Digital Elevation Models (DEM) derived from stereo pairs of SPOT-5 (HRS1 and HRS-2) and Cartosat-1 (Fore and Aft) over the test site located in Bavaria, Germany. This is one of the test areas selected towards SPOT-5 Assessment Programme. DEMs are generated with two different kind of modelisation; one with geometric correction of images using physical sensor model and other one with Rational Polynomial Coefficients (RPC). In the first approach, Ground control points (GCP) are used for bundle adjustment with a self calibration to improve the interior and exterior orientation parameters. In the second approach, RPC's are derived initially from the grid generated through direct georeferencing using the physical sensor model and then compensated with GCPs. Out of the 47 points provided, 5 are used as GCPs for rectification of SPOT images and 3-D modeling was checked on remaining 42 independent points. Both orientation methods gave RMS errors less than a pixel for both mono and stereo orientation. We tried to transfer these points to Carto-1 fore and aft images through sub-pixel matching. But most of the points could not be precisely transferred to Cartosat-1 as the GCP locations are not clear cut features on the SPOT image. Secondary controls are derived by identifying few well defined road junctions in SPOT scenes and deriving the corresponding ground co-ordinates through SPOT stereo intersection which gave an accuracy of 2-3m. They are manually identified in Cartosat-1 images. Two stereo GCPs are used for modeling Cartosat-1 fore and aft images. Accuracy is evaluated at the remaining points for different subscens. RMS errors of the order 6 to 7m in X, Y, Z are obtained. Increasing the number of GCPs does not improve the accuracy. The DEMs are generated using a combined approach of feature based and area-based multi-scale image matching method and semi automatic editing tools. The quality of the matching is controlled by forward and backward matching of the two stereo partners using the least squares matching method. The "no match" areas are filled with interpolation during the DEM production process and final DEM is generated at regular interval. DEM accuracy is determined by using the available DEM data of superior accuracy. Detailed visual and quantitative comparison results of the DEMs from SPOT-5 and Carto-1 are presented in the paper. Even though absolute accuracy is poor for Cartosat-1 due to the inaccuracy of secondary controls, quality of the DEM is much superior to SPOT-5 DEM. Statistics of the errors are analyzed and tabulated for the DEMs generated with different global spacing.

1. INTRODUCTION

As part of Assessment Programme of SPOT-5 (CNES-ISPRS-HRS Study Team) and Cartosat-1 (ISPRS-ISRO-Cartosat-1 SAP), various international specialists have evaluated and reported the accuracy of the DEMs generated from these satellites (Jacobsen, K., 2004; Poly, D., 2004; Reinartz, P., 2004; Srivastava, P. K., et al., 2007; Lehner, M. et al., 2006; Crespi, et al., 2008; Nanda Kumar, et al., 2008). Both satellites provide along-track stereo pairs. HRS produces image stereo pairs with two optics looking forward and backward (± 20 degrees) with respect to the nadir direction. The camera has a spatial resolution of 10 meter across track and along track, but a ground sampling distance of about 5 m along track. Cartosat-1 has two fixed panchromatic cameras for along-track stereo acquisition; Forward camera (F) and an Aft camera (A) with tilts in flight direction of $+26^\circ$ and -5° respectively. There is 52sec gap in imaging the same area by the other camera. The focal plane is composed of a staggered CCD array configuration of 12,000 pixels with 7

microns pixel spacing, separated into 6000 each of odd and even pixels. These odd and even pixel rows are separated by $34\mu\text{m}$ (equal to 5 pixels) in the focal plane. Resolution of Cartosat-1 is about 2.5m. B/H ratio of SPOT-5 is about 0.85 and that of Cartosat-1 is 0.62.

In this paper, generation, evaluation and comparison of DEMs from SPOT-5 and Cartosat-1 stereo pairs is reported. For orienting the imagery, two alternative approaches have been used: one with a rigorous sensor model and the other one with Rational Polynomial Coefficients (RPC). A generic sensor model for georeferencing of linear CCD array images has been developed. This model is very flexible and has been successfully used for the orientation of SPOT-1, IRS-1C/1D, TES, IRS-P6 (Radhadevi et al., 1994, Radhadevi, 1999, Radhadevi et al., 2008) The algorithm is purely based on the viewing geometry of the satellite, combining the principles of photogrammetric collinearity equations, originally developed for SPOT-1 and further adapted and tested for different sensor geometries. For SPOT-5, as the precise interior orientation parameters are not known, a modified sensor model is used

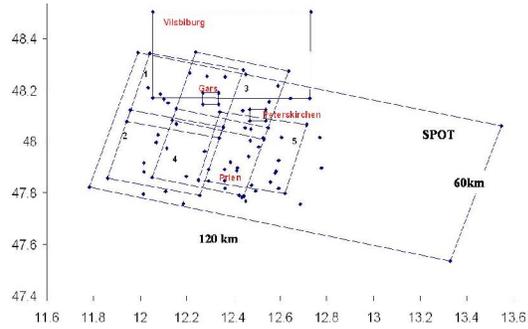
with a self-calibration approach in which interior orientation parameters (effective focal length and modified centre pixel) are also updated along with the exterior orientation parameters. For Cartosat-1, generic sensor model itself is used along with in-flight calibrated camera parameters fixed. The alternative method, independent from the camera model, does not describe the physical imaging process, but uses rational polynomials to relate image and ground coordinates to each other. This algorithm consists of two steps: 1) calculation of Rational Polynomial Coefficients (RPC) for each image with least-squares using the geometric information contained in the metadata files; 2) RPC compensation using GCPs. The derived DEMs are then compared with the high precision reference DEM by several methods regarding: height accuracy, location accuracy, blunders, error budget depending on surface properties etc. After the description of the available data, the processing algorithms applied for images orientation, matching and DEM generation are presented. The results obtained after the comparison between the generated DEMs with the reference ones are reported and analysed. Details of the RSM and RFM are available in Radhadevi & Solanki, 2008 and Nagasubramanian et al.2007.

2. TEST AREAS AND GROUND REFERENCE DATA

Data provided by Dr. Jacobsen contains stereo images from SPOT5-HRS sensor with corresponding metadata files, the description of the exact position of 47 object points measured with surveying methods and the reference DEMs produced by Laser data and conventional photogrammetric and geodetic methods. The image co-ordinates of the GCP locations are also provided for HRS-1 and HRS-2 images. The points are in Graus-Kruger projection and Bessel datum. SPOT images were acquired on 1st October 2002 with a sun elevation of 38° and nearly no clouds.

Test regions are chosen for DEM generation over Bavaria area. The elevations range from 400 to 1700 meters. This area contains different types of terrain which allows the comparison of DEM for different land surface shapes, including forest and steep terrain. 4 regions over this area are analyzed. Reference DEM 1 has an overall size of about 5km X 5km over Gars area with a spacing of 5m derived from airborne laser scanning. Reference DEM 2 has also the same size over Prien area. Reference DEM 3 also covers an area of about 5km X 5km over Peterskirchen. The height accuracy of all these DEMs is better than 0.5 meter. Reference DEM 4 is of 50kmX30km. But only a part of this is covered by SPOT-5 as well as Cartosat-1 images. Accuracy of this DEM is about 2-3m.

The corresponding area is covered by 5 sub scenes of Cartosat-1. Coverage of SPOT-5 and Cartosat-1 data along with GCP locations and reference DEM locations are shown in Fig.1. Cartosat-1 data have been acquired on 30th January 2006, 26th July 2007 and 1st August 2007.



Cartosat-1:

- 1.Path/Row :157/178 Dated 30th Jan06
- 2.Path/Row :157/179 Dated 30th Jan06
3. Path/Row:158/178 Dated 1st Aug07
- 4.Path/Row :158/179 Dated 1st Aug07
- 5.Path/Row :159/179 Dated 26th July07

Fig.1 Overview of SPOT-5 and Cartosat-1 sub scenes coverage along with available SPOT GCP locations and reference DEMs

2.1 GCP identification in Cartosat-1 images

Most of the points are not on clear cut feature locations in SPOT image (may be identified through aerial survey on signalized points). Since image locations were also provided in the input SPOT-test data, SPOT orientation could be done without any issue. Data from Cartosat-1(scene1) was fully covered with snow. The scene snow coverage lowered the usefulness for acquiring information concerning land use and also created a problem for automatic transfer of the GCPs from SPOT-5. Due to different resolutions and orientations of the HRS and Cartosat-1 images (5m along-track and 10m across-track for SPOT-5 and 2.5 for Cartosat-1), epipolar registration is done between them by geocoding and submitted for sub pixel hierarchical matching. The conjugate point locations are then transferred to raw space through reverse mapping. Local area fitting is done with affine transformation between the match points and the coordinates corresponding to GCPs are computed in Cartosat-1. Due to terrain effects in the geocoded products with different view angles of SPOT and Cartosat-1, many points gave mismatches. Therefore, another method was attempted in which clear cut conjugate points are identified in SPOT-5. Corresponding ground co-ordinates are determined through stereo intersection. Image co-ordinates are identified in Cartosat-1 images corresponding to these points and these secondary controls are used as GCPs and checkpoints for Cartosat-1. By automatic image matching, digital surface models are generated with height values of the visible surface.

3. DEM EVALUATION AND RESULTS

Evaluation is done at independent checkpoints using sensor model, and also by comparison of generated raster DEM with reference data.

3.1 Results on Stereo-model computations

3D modeling accuracy was tested on independent checkpoints. Table 1 gives the RMS errors of the least square adjustment computations for SPOT-5 and Table 2 gives the computation accuracy of Cartosat-1. Errors are estimated at the checkpoints. RMS errors at the checkpoints reflect the restitution accuracy. For SPOT-5, accuracies of the order 2-3m is achieved with 5GCPs. As we see in Table 2, for Cartosat-1, by choosing one

conjugate GCP, geometric accuracy increases significantly. Here, input GCPs as well as check points are secondary controls derived from stereo intersection of SPOT-5 images. Accuracy of them is of the order of 3-4m. Just with 1 conjugate GCP, Cartosat-1 stereo restitution accuracy is about 6-7m which are of the same order of input GCP/data errors, being a combination of image pointing error and planimetric error in addition to the propagation of Z-error depending on the viewing angles. This accuracy is dominated by the limited control point quality. Increasing the number of GCPs does not increase the accuracy considerably.

Number of GCPs+ CPs	RMS Lat(m)	RMS Lon(m)	RMS Ht. (m)	Min.Ht. err (m)	Max.Ht. err (m)
5+42	1.53	3.22	2.87	-3.27	7.92
6+41	1.36	2.73	2.66	-4.13	6.81
7+40	1.40	2.73	2.69	-3.74	7.41
8+39	1.69	2.83	3.13	-2.43	9.01

Table 1 Errors at check points using rigorous orientation model for stereo intersection (HRS1 &HRS2)

Path/Row	Number of GCPs + CPs	RMS Lat (m)	RMS Lon(m)	RMS Ht. (m)	Min.Ht. (m)	Max.Ht. (m)
159/179 (scene 5)	2+9	4.3	7.3	7.3	-12.3	0.5
	3+8	8.3	5.4	8.4	-10.8	0.06
	4+7	8.7	4.9	7.7	-8.3	-3.3
	5+6	6.4	5.6	9.0	-11.9	3.4
157/178 (scene 1)	2+9	5.3	7.3	5.6	-9.9	-3.5
	3+8	7.8	7.7	5.2	-7.9	-3.7
	4+7	7.6	7.5	4.9	-6.3	-4.9
	5+6	7.0	8.0	4.5	-0.3	-3.8
158/178 (scene 3)	2+9	6.6	6.9	9.8	-16.5	4.2
	3+8	6.7	6.9	11.1	-18.9	4.6
	4+7	6.5	7.3	7.2	-8.4	2.3
	5+6	6.5	7.7	8.3	-13.0	5.9

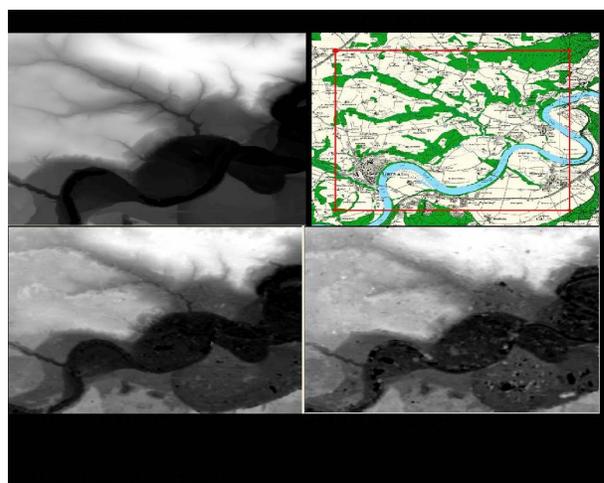
Table 2 Errors at check points using rigorous orientation model for stereo intersection of Cartosat-1 (Aft+Fore)

3.2 Results on DEM evaluation

The accuracy numbers are only one indicator for the quality of a height model. The SPOT-5 HRS sensors have a spectral range from 0.48 up to 0.70µm wavelength, that means only the very first part of infrared is included, while Carosat-1 has a spectral range from 0,50 up to 0.85µm, including the near infrared. In the near infrared the vegetation has a strong reflectance. By this reason the automatic image matching with Cartosat-1 images over forest areas is very successful. In SPOT-5 HRS images the forest is always dark, causing severe matching problems.

We analyze the qualitative and visual evaluation of the DEM and quantitative and statistical evaluation of the DEM with the

reference DEM. Matching is done at different intervals, viz; 5m,15m,30m and 50m. The tonal variation of vegetation constrains the matching to a low correlation factor. The areas where correlation is poor, the match point may not be the correct terrain point. Thus, a low pass filter is used to free it from blunders. Analysis with reference and stereo DEM points are done with the help of Arc/Info. The contours replicate the pattern as the reference DEM. The planimetric accuracies are estimated from contour nearness of corresponding lines. Vertical accuracy of this stereo data DEM is concluded from statistical analysis of difference DEM that is derived from the deviations in heights of data derived points from that of the reference points.



CARTO -1 DEM (5 m spacing) SPOT-5 DEM (5m spacing)

Fig.2 Generated DEMs over Gars area

Figure 2 shows the DEM generated with 5m spacing over Gars area from SPOT-5, Cartosat-1, corresponding map and the reference DEM. The generated height model is describing the visible surface from the camera and not the bare ground required for a DEM. It is obvious from this figure that the generated DEM well reproduces the terrain relief and topographic features. Horizontal height profile over Gars is compared for Cartosat-1 DEM and reference DEM in figure 3. DEMs generated over Prien area and Vilsbiburg area are shown in figures 4 and 5 respectively. Figure 6 shows the horizontal height profiles over the DEMs of Prien area.

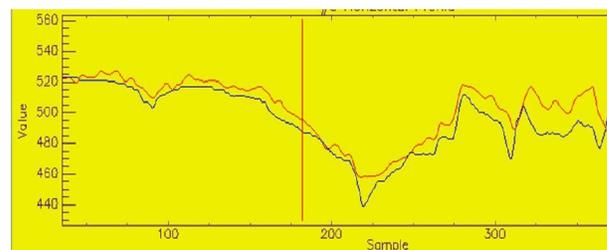


Fig.3 Horizontal height profile over GARS (Red-Carto DEM & blue Ref DEM)

The DEM generated is compared to the reference DEM and statistics are derived using Arc/Info. As output, the s/w gives the number of points compared, minimum difference, maximum difference, and mean difference, standard deviation and RMS errors. DEM is assessed according to the land cover and slope categories. Table 4 gives the accuracies of the generated height models of SPOT-5 and cartosat-1. The frequency plots over sloped and flat areas of a small window over Prien were analysed. For both cases, it was seen that mean difference is more for Cartosat-1 DEM but standard deviation is less for Cartosat-1 DEM compared to SPOT. DEM accuracy depends on terrain slope and type of terrain. Standard deviations of filtered height models in open areas give very good accuracy. The DEMs comparison shows that the derived DEM from Cartosat-1 is very much close to the reference one. With respect to the thematic content, the image quality is good. The 10-bit dynamic range enables the detection and identification of features and terrain patterns as they are visible. Cartosat-1 reproduced quite well not only the general features of the terrain relief but also small geomorphological and other features visible in the terrain.

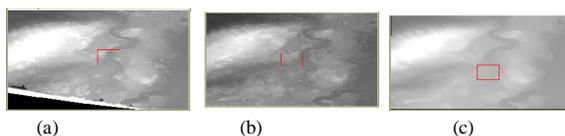


Fig.4 Generated DEMs over Prien area
(a) Cartosat-1 DEM (b) SPOT-5 DEM (c) Reference DEM

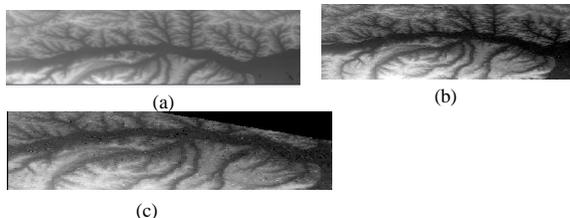
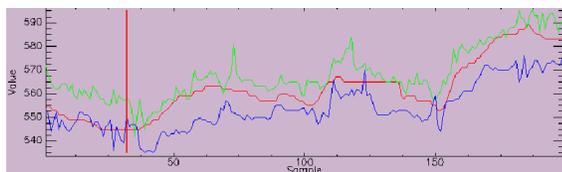


Fig.5 Portion of Vilsbiburg area (a) Reference DEM (b) Cartosat-1 DEM (30 m spacing) (c) SPOT-5 DEM (30m spacing)



— Reference
— Cartosat1
— Snot5

Fig.6 Horizontal height profiles over the DEM s of Prien area

Reference DEM	Reference area	Size and Accuracy of Ref. DEM	Cartosat-1	Points [#]	SPOT-5	Points [#]
			Mean Height Difference (m)		Mean Height Difference (m)	
DEM-01	Gars	5 x 5 km, 0.5 m	-2.2	48000	2.3	37000
DEM-02	Prien	5 x 5 km, 0.5 m	-7.8	18624	4.9	14567
DEM-03	Peterskirchen	5 x 5 km, 0.5 m	-5.6	45396	4.9	97000
DEM-04	Vilsbiburg	50 x 30 km, 2-3m	-0.9	25000	- 4.2	23100

Table 4: Comparison of height for high quality points between reference DEM, SPOT-5 DEM and Cartosat-1 DEM Over flat area

4. CONCLUSIONS

In this paper we have compared Digital elevation models generated from stereo pairs of SPOT-5 (HRS1+HRS2) and Cartosat-1 (Fore+ Aft) over Bavaria site. The DEM generation is done using a physical sensor model based on collinearity equations and also using RPC coefficients. The hierarchical matching is done after epipolar registration. A quantitative and qualitative evaluation of the DEM generated was conducted by comparison with a reference DEM. RSM and RFM give almost comparable results. The absolute accuracy of the generated DEM is about 3-4 m for SPOT-5 and 6-7 m for Cartosat-1 where GCPs as well as check points of Cartosat-1 are of accuracy of 3-4 m. All height models based on space information are digital surface models, showing the visible surface of the vegetation and artificial objects. A filtering of the DSMs in the closed forest area has limited effect because only few object points are really located on the bare earth. Nevertheless the morphologic details in the Cartosat-1 height model are at least on the level of the existing DEM of the topographic map 1 : 25 000. The SRTM C-band height model or SPOT-5 height model of course cannot show the same level of detail. Quality evaluation of generated DEMs reveals that information content in Cartosat-1 is much superior to SPOT-5 DEM. But geometric fidelity of SPOT-5 HRS images is really surprising. It is proven with this research that it is possible to extract good quality DEM using along-track stereo pairs of Cartosat-1 and SPOT-5.

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