CARTOSAT-1: ORIENTATION, DEM AND ORTHORECTIFICATION QUALITY ASSESMENT

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ABSTRACT:

CARTOSAT-1 is an Indian satellite – the 11th one in the IRS (Indian Remote Sensing) series designed to provide quality Earth imagery for telemetry and digital mapping. The satellite carries two panchromatic sensors capturing images forward (26 degrees) and backwards (5 degrees). Images are recorded almost simultaneously in both directions along the satellite's orbit plane or with an inclination, if needed. The sensors cover the swath about 30 km wide with the resolution of 3 m (+26 degrees) and 2,5 m (-5 degrees). This article summarizes the findings of the research programme aiming to verify the quality of the imagery acquired by Cartosat-1. The verification was conducted using a test scene located in Poland. The research team included engineers from Geosystems Polska and scientists from Military University of Technology, Warsaw. The imagery was processed with Leica Photogrammetry Suite software.

1. INTRODUCTION

To assess the quality of imagery from Cartosat-1 and its viability for Earth's Digital Elevation Models ISRO and ISPRS started a research programme named C-SAP (Cartosat Scientific Assessment Programme) inviting companies and institutions with appropriate human and technical resources. Sixteen Principal Investigators were chosen to provide reference data. The authors were part of the Principal Investigator responsible for the Test Site 9 (TS-9).

2. INPUT DATA

2.1 Image Data

The coordinator of the CSAP-ISRO programme provided a stereoscopic pair of images acquired on February 25th, 2006. The pair covers an area located slightly over 100 km South-West of Warsaw, the capital of Poland. The scenes were rated good quality though due to the winter season most of the area was covered with snow.
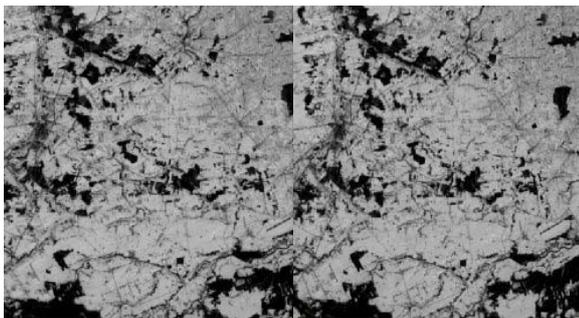

Figure 1. The after (left) and forward image.

2.2 Reference data

DEM: As required by C-SAP the Principal Investigator (PI) responsible for TS-9 provided two reference terrain models from two independent sources: a Digital Elevation Model (DEM) with the resolution of 25 m generated from topographic maps and a DTED-2.

GCPs: To provide flexibility in data analysis, 36 Ground Control Points (GCPs) were established. The GCPs were distributed evenly over the stereopair. After a field survey the number of GCPs was reduced to 31 due to difficulty in identifying the correct location of 5 of them. As a general rule, GCPs were placed where roads or paths crossed, though in some areas only fence corners provided enough reliability.
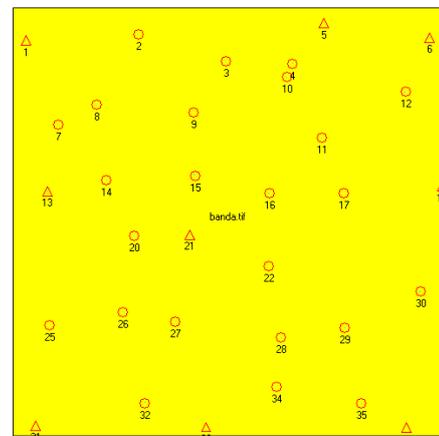

Figure 2. GCP distribution in the scene.

The GCP field survey was conducted with a GPS receiver using

the FastStatic method. The resulting horizontal accuracy of 0.10 m and the vertical accuracy was found at 0.15 m. Each GCP was well documented with photographs and drawings to provide additional data for C-SAP programme members.

Additional field survey: During the field survey 3 elevation profiles were measured using GPS RTK method. Each profile was 3.5 km long with reference points every 20 m.

3. SOFTWARE USED

The first phase included: the stereopair orientation, generation of a DSM and orthorectification. All image processing for TS-9 was conducted with Leica Photogrammetry Suite (LPS) 9.0 software. The results and first insights were presented in September 2006 during the ISPRS symposium held in Goa, India (Dabrowski et. al 2006).

In 2008 some calculations were repeated with the newer version of the LPS software (v.9.2 Service Pack 1). Both software versions used the RPC method. According to ERDAS, Inc. (the manufacturer of LPS), LPS 9.2 SP1 introduced changes in the triangulation algorithm for the RPC method as well as sensor model enhancements for Cartosat-1. To investigate the differences between the results from the two versions of LPS software, some calculations done originally with LPS 9.0 were repeated using LPS 9.2 SP1.

4. ORIENTATION

The orientation of the stereopair was established using 4 sets of GCPs: 4, 9, 16 and 25, spread evenly across the stereopair (Fig. 2). The GCPs left out of the sets were selected as independent Check Points. The RMSEs (Root Mean Square Errors) obtained during triangulation for the Check Points were used as the measure of accuracy of the orientation. Table 1 includes detailed results.

# of GCPs	RMSE X	RMSE Y	RMSE Z
4	1,49	1,32	1,48
9	1,46	1,22	1,16
16	1,38	1,18	1,11
25	1,21	1,22	1,08

Table 1. The RMSEs calculated for independent Check Points.

Clearly, each set provides sub-pixel accuracy of scene orientation. Similar results were obtained with the same data for TS-9 using different software tools (Jacobson 2006, Titarov 2007). The results suggest 4 to 9 well defined GCPs for scene orientation were enough for imagery from the Cartosat-1 satellite. In the following sections the variant with 9 GCPs is referenced

5. SETTING UP THE STEREO MODEL

After the orientation phase, the accuracy of the reconstruction of the stereo model was tested. The independent test was based on manual elevation measurements made at Check Points. The results are summarized in Table 2.
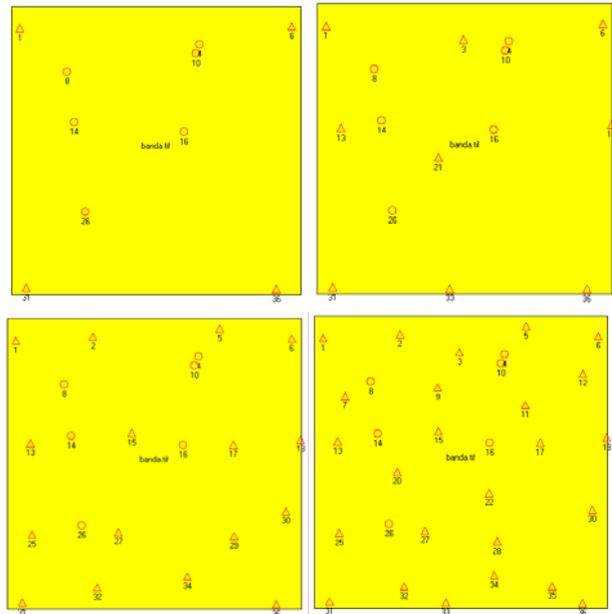

Figure 3. The GCP and Check Point distribution in each 4 sets (GCPs = triangles).

Point ID	H GPS	H Model	dH [m]
4	163,55	163,07	0,48
8	162,63	163,56	-0,93
10	165,79	165,10	0,69
14	138,05	138,30	-0,25
16	169,65	171,23	-1,58
26	163,82	165,20	-1,38

Table 2. The differences in elevation at GCPs between the stereo model and the field survey.

The small differences between elevation values obtained from the satellite imagery and the ones recorded during the field survey clearly imply the stereo model's accuracy as well as the eligibility of the model for DSM extraction. The following sections analyze quality assessment of the DSM in more detail.

6. DSM EXTRACTION

The next phase of the experiment was DSM extraction using the autocorrelation method and assessing the resulting model for accuracy. The DSM was based on the scene set with 9 GCPs which had been found optimal in the previous phase. The DSM was calculated with LPS 9.2 SP1, using the exact same configuration as in 2006 with LPS 9.0 (Search Area: 21x3, Correlation Window 7x7, Correlation Threshold 0.85) (Dabrowski 2006/1).

The results from LPS 9.0 (lesser than LPS 9.2 SP1) were found incorrect to a large degree as far as elevation was concerned. The discrepancies were in hundreds of meters and covered relatively large area. After visually inspecting both images of the stereopair two types of errors were found, both of which were independent of the satellite sensor, but rather resulting from software.

The first type of errors resulted from the presence of clouds, or rather their shadows on the ground as captured on the stereopair.

At first glance the images were cloudless. This impression resulted from the low contrast between the shadow-projecting clouds and the snow-covered ground. The older version of LPS software apparently did not manage to filter excess values.

The other type of errors which came to light with the LPS 9.0 was inaccurate elevation extracted along linear objects oriented along the left and right edges of the stereopair i.e. parallel (+/- 5 degrees) to the satellite's orbit (Fig. 3).
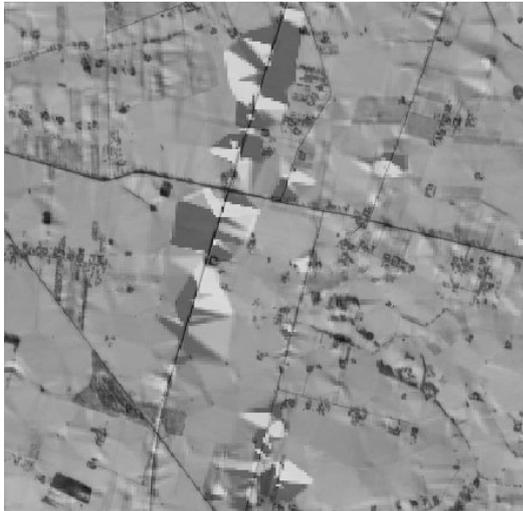

Figure 3. Gross errors identification using Blend Tool in ERDAS Imagine

Both types of errors identified during the experiment resulted not from the sensor mounted on the satellite, but rather from the inaccurate sensor modeling by software or its correlation algorithm improperly designed. Additional confirmation to these claims is the non-existence of the said errors in the newer version of LPS (v. 9.2 SP1 or later) based on the same source data. The new model significantly differs from the previous ones (Fig. 4).
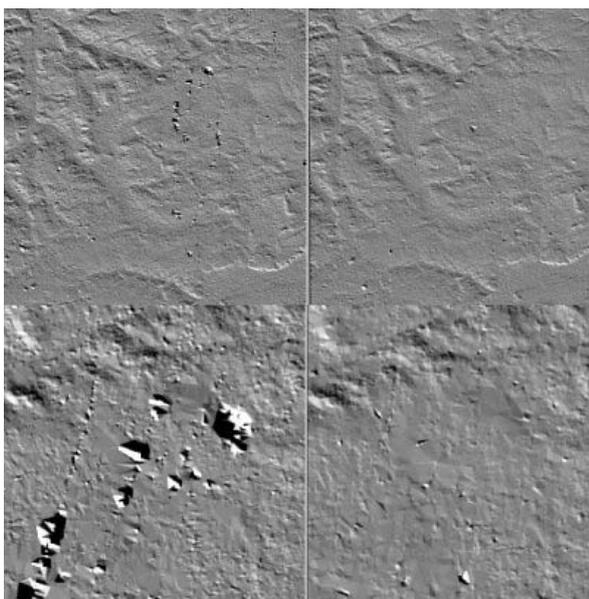

Figure 4. DSMs calculated in LPS 9.0 (left) and LPS 9.2 SP1.

The differences between models generated by two different versions of LPS are obvious. With LPS 9.0 areas with gross errors are apparent while the LPS 9.2 SP1 image is much more smooth, representing better accuracy of the elevation model. Correlation analysis of both the old and the new models with the original stereopair shows major improvement (coefficient of correlation at 0.85). The LPS 9.2 SP1 image did not have a single object in the suspicious class which is coherent with the software's manufacturer statement, regarding the improved correlation algorithm for Cartosat-1 introduced with LPS 9.2 SP1.

General Mass Point Quality	%
Excellent % (1-0.85)	87.2
Good % (0.85-0.70)	12.5
Fair % (0.70-0.5)	0.3
Isolated %	0.0
Suspicious %	0.0

Table 2. Correlation quality

7. DSM ACCURACY ASSESMENT

Accuracy of the DSM generated from Cartosat-1 imagery was measured against the two DEMs. Each model was obtained independently of the other. After the initial analysis of the DSM its accuracy was tested against the reference model based on topographic maps with the scale of 1: 25000. The difference between the DSM based on the LPS 9.2 SP1 and the reference model was very narrow. The graph below illustrates the distribution of the differences, most of which tended to stay within the +/- 3 m range. That fact proved the high fidelity of the obtained elevation models.
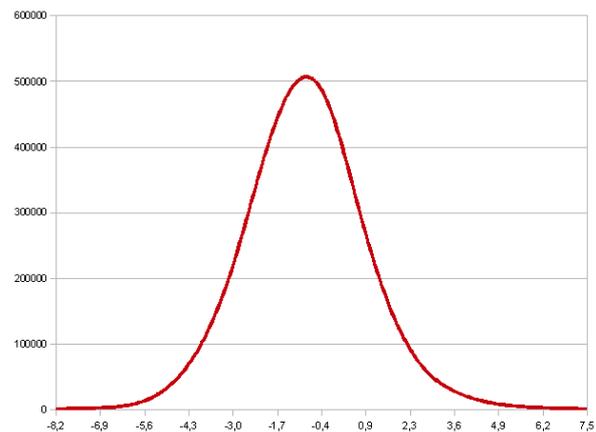

Figure 5. The reference DEM and the calculated DSM difference distribution.

The next phase was aimed at verifying the calculated model's accuracy at the 6 previously chosen Check Points. The results of the verification are in the Table 3. Only one of the Check Points shows noticeable deviation from the others with the value of the difference above 2 m. In all other cases the differences stay within the 2 m range, which is further evidence of the high fidelity of the model.

Pt, ID	X	Y	DSM Z	DEM Z	Residual
4	464147,98	5738939,12	163,55	163,06	-0,49
8	451384,13	5739462,83	162,63	162,9	0,27
10	463566,51	5738103,00	165,79	165,26	-0,53
14	450570,68	5734109,76	138,05	138,32	0,27
16	460284,13	5730408,02	169,65	167,44	-2,21
26	449046,65	5724779,93	163,82	164,24	0,42

Table 3: Detailed Check Point accuracy information

The DSM assessment included inspection of the cross sections measured during the field survey. The cross section distribution in the stereopair was as on the illustration (Fig. 6.).
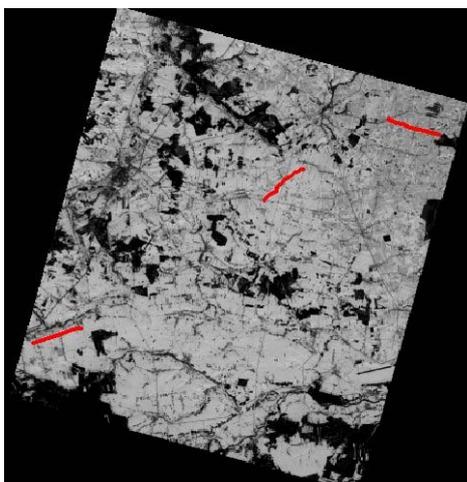

Figure 6: Cross sections distribution on after scene.

The cross sections are 3.5 km long each and the distance between the measured points is about 20 m. The automatically calculated cross sections and the ones measured during the field survey using GPS PSK method were found strongly correlated.

The graphs below summarize the correlation between the DSM and the GPS RTK measurements taken during the field survey. All graphs illustrate values calculated using LPS 9.2 SP1. Clearly the correlation is very strong – up to 0.95 (Fig. 7). This ultimately proved the high fidelity of the DSMs based on stereopairs acquired by Cartosat-1 satellite.
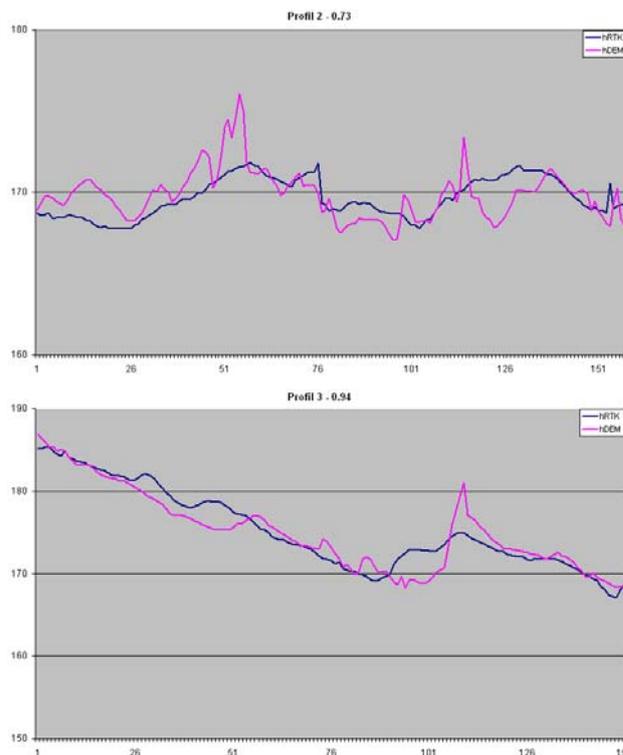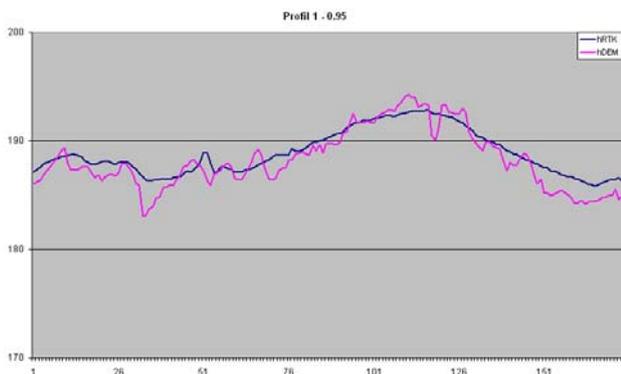

Figure 7: Cross sections and their correlation values.

8. ORTHORECTIFICATION

The orthorectification was conducted using the DSM, which was calculated with LPS 9.2 SP1. The resolution was set to 2.5 m and the after scene and 3 m for the forward scene. Both orthoimages matched precisely which implied the accuracy of the DSM was sufficient for high resolution orthoimaging. The images were also highly compatible with the field survey data.
As an additional measure the orthoimage from the satellite was visually compared to independently acquired orthoimages from another IRS satellite (IRS P-6 Resourcesat). The results again confirmed the high accuracy of the orthoimage.

9. CONCLUSION

The findings included in this paper reflect the high accuracy of stereo data produced by Cartosat-1. The images acquired by the satellite can be safely used for the purposes it has been designed for (Srivastava, 2007) i.e. gathering elevation data with accuracy sufficient for maps with the scale of 1:25000. Digital Elevation Models based on the stereopairs from Cartosat-1 are sufficient for generating orthoimages with the resolution of 2.5 m (Cartosat-1, SPOT) or lower (IRS).

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