

MULTI-SCALE DIGITAL TERRAIN MODEL GENERATION USING CARTOSAT-1 STEREO IMAGES FOR THE MAUSANNE LES ALPILLES TEST SITE

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ABSTRACT:

Cartosat-1 is the first Indian Remote Sensing satellite able to collect in-track high resolution stereo images with a 2.5m pixel size. Since Cartosat-1 has no multispectral cameras, it was mainly developed for topographic mapping and Digital Terrain Model (DTM) generation. In the framework of the Cartosat-1 Scientific Assessment Programme, the Politecnico di Milano University (Italy) evaluated as Co-Investigator the performances of the Cartosat-1 satellite in the generation of DTMs from stereo-couples. This paper describes in detail the outcomes for the Mausanne les Alpilles (France) test site, with respect to existing standards and products actually used in France and also provides a comparison with the global Shuttle Radar Topography Mission's DTM supplied by NASA and widely used in the remote sensing community.

1. INTRODUCTION

Cartosat-1 is the first Indian Remote Sensing (IRS) satellite able to collect in-track high resolution stereo images with a 2.5m pixel size. Since Cartosat-1 has no thematic capabilities (no multispectral cameras), it was mainly developed for topographic mapping and Digital Terrain Model (DTM) generation.

At the beginning of 2006 an agreement has been reached between the International Society for Photogrammetry and Remote Sensing (ISPRS) and the Indian Space Research Organisation (ISRO) to jointly conduct the Cartosat-1 Scientific Assessment Programme (C-SAP), whose purpose was to evaluate the Cartosat-1 mapping capabilities in the following processes:

- Photogrammetric stereo triangulation at scene level;
- Photogrammetric stereo triangulation at block level (multiple scenes);
- Extraction of terrain features for topographic mapping;
- DTM generation;
- Topographic mapping.

Within the C-SAP framework, Politecnico di Milano University (Italy) was selected as Co-Investigator for the French test site of Mausanne les Alpilles (C-SAP TS5) and this paper describes the outcomes of the investigation carried on in the assessment of the DTM's generation.

Results were compared with respect to existing standards and products actually used in France (i.e., the French Institut Géographique National's and Spot Image's Reference 3D®). Moreover, the investigation also provided a comparison with the global Shuttle Radar Topography Mission (SRTM) DTM supplied by NASA and widely used in the remote sensing community (Van Zyla, 2001).

Imagery collected with Cartosat-1 were used for the generation of: i) high-resolution DTMs (from 2.5m to 10m grid cell size),

ii) medium-resolution DTMs (25m grid cell size), and iii) low-resolution DTMs (90m grid cell size) using commercial off-the-shelf software. This choice was made to provide to the remote sensing users a comprehensive study about the potentialities and limits of the Cartosat-1 image processing using standard image processing software.

2. DATASET

2.1 Test site

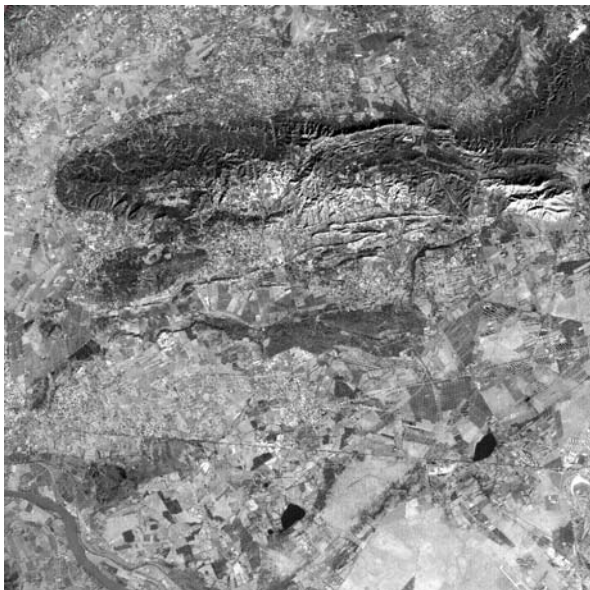
Mausanne les Alpilles sits in the hart of Provence (France), in the triangle of Arles, Avignon and Marseille. An area of about 650 km² of overlap between the Cartosat-1 images and the reference DTMs has been selected as test site (upper left: 4,854,403m N, 633,411m E; lower right: 4,835,486m N, 655,172m E). Here the elevation ranges from 47m in the south-west to 633m in the north-east and the territory presents a mixture of rural areas (60%), green forest (35%) and urban areas (5%).

2.2 C-SAP dataset composition

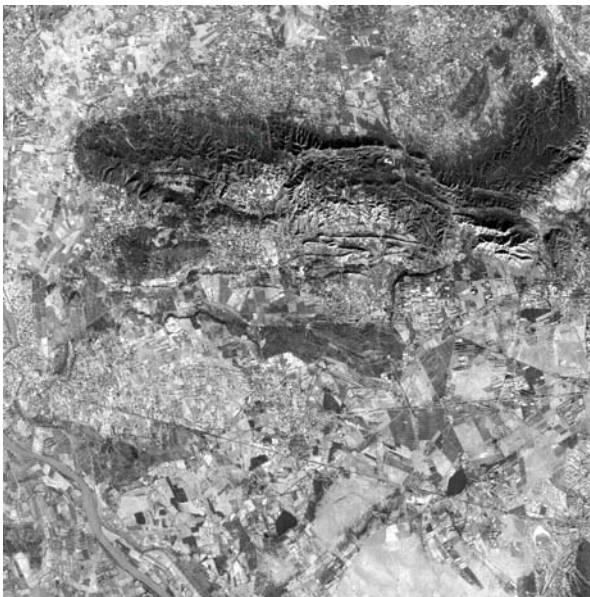
The standard C-SAP TS5 dataset was composed of the following:

- One 2.5m Cartosat-1 stereo pair collected over Mausanne les Alpilles on January 31, 2006 (Path=0127, Row=0198), provided by ISRO (Figure 1);
- A set of 32 high precision Ground Control Points (GCPs), provided by the Principal-Investigator (PI) European Commission-Joint Research Centre (EC-JRC). Figure 2 shows the GCPs distribution on the study area;
- A high-resolution DTM (ADS40_DTM) with 2m grid cell size and produced using a Leica ADS40 digital camera, provided by the PI EC-JRC (Figure 3).

In addition to the standard C-SAP TS5 dataset, it was also used a 90m grid spacing radar DTM generated from the SRTM and available from NASA (Figure 4).



(a)



(b)

Figure 1. Cartosat-1 stereo orthokit collected over Mausanne les Alpilles (France) on January 31, 2006. (a) Aft panchromatic image, (b) Fore panchromatic image.

2.3 Standard accuracy of Cartsat-1 images

ISRO delivered to the study team Cartosat-1 imagery as Stereo Orthokit product in GeoTIFF format and also supplied predetermined Rational Polynomial Coefficients (RPCs) (Indian Space Research Organisation, 2005). The GeoTIFF Orthokit product is a radiometrically corrected data and is supplied to

users to produce high precision cartographic products and DTMs. Its location accuracy is better than 250m ($3\sigma=220m$ for system level correction, Level 1) (Krishnaswamy and Kalyanaraman, 2002; National Remote Sensing Agency, 2007).

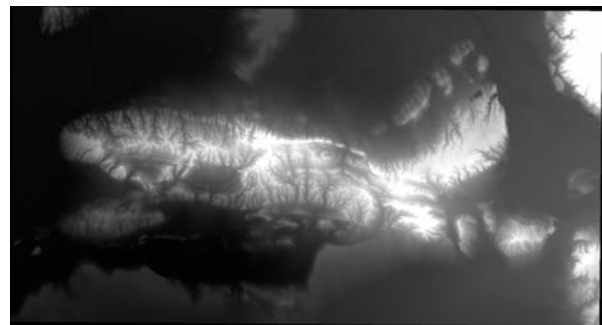


Figure 2. High-resolution reference DTM (ADS40_DTM) for Mausanne les Alpilles (France) test site produced using a Leica ADS40 digital camera.

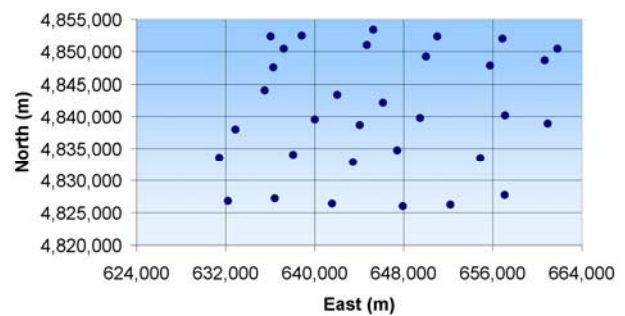


Figure 3. Ground control points distribution over the study area.

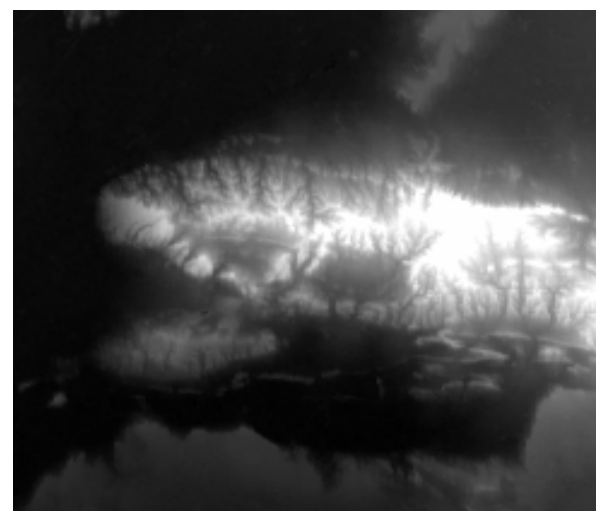


Figure 4. Low-resolution global Shuttle Radar Topography Mission (SRTM) DTM supplied by NASA.

3. METHODS

3.1 Data processing

The Cartosat-1 data processing was performed with the commercial off-the-shelf software ENVI 4.3® and involved the following aspects: i) image pre-processing, ii) optimization of the DTM's extraction procedure and, iii) the analysis of the influence of GCPs in the modelled DTM.

Before generating the DTMs from the Cartosat-1 images it was studied the influence of the parameters involved in the generation process (i.e., number of tie points used, search window and moving window sizes, correlation coefficient and terrain detail). A sensitivity analysis led to the final optimal configuration as shown in Table 1.

The 60 tie points used in all the tests have been automatically detected using a regular grid scheme which covered the entire images. By increasing their number it was not observed any improvement in the Y parallax (1.08 pixel).

Regarding the computational time it is to be said that reducing the terrain detail level, from level 7 to level 6, it was obtained a decrease of the processing time by a factor of 4.6 and without any sensible decrease in the final DTM's accuracy.

Parameter	Value
Number of tie points	60
Search window size	800 pixel
Moving window size	30 pixel
Correlation coefficient	> 0.8
Terrain detail	level 6 (over 7 levels)

Table 1. Optimization of the DTM's automatic extraction procedure.

3.2 Ground control points selection and their accuracy

This study investigated the multi-resolution DTM's generation with respect to the influence of the number and configuration of the GCPs used. Thus, different configurations were tested in order to reach the best results with the fewer number of GCPs (Lang, 1999).

The GCPs supplied by the PI have been measured with GPS instruments and have a vertical accuracy of 0.05m (Kay and Zielinski).

3.3 Validation of results

Results obtained from the data processing of the Cartosat-1 stereo images were checked with respect to:

- A set of independent check points (ICPs) extracted from the original C-SAP dataset. These data were used for all the DTMs generated;
- The ADS40_DTM;
- The NASA's SRTM DTM.

All the dataset were first converted into the UTM-WGS84 F31N reference system. From the high-resolution ADS40_DTM four downsampled DTMs were generated in the range of 2.5m - 10m. In addition, a medium-resolution DTM with 25m grid spacing was derived from the high-resolution DTM. For the validation of the low-resolution DTM, two reference DTMs were used: i) a downsampled version of the ADS40_DTM (90m

grid resolution) and ii) the SRTM DTM resampled from its original resolution (60m x 90m) to 90m grid resolution.

Regarding the accuracy of reference DTMs, the Linear Error ($LE\alpha$) is a measure typically used for accessing the overall accuracy of elevation data at the fixed confidence level α . It is assumed that the North and East coordinates are correct and a comparison in the elevation is performed towards reference measures: an $LE90=2.5m$ implies that 90% of the measures to be tested vary from the reference measures by 2.5m or less.

Accuracy of references DTMs are as follows:

- ADS40_DTM: this is a high resolution DTM with a RMSE=0.6m in elevation, as from PI's specifications;
- SRTM DTM: absolute $LE90=6.2m$ in elevation for Eurasia (Rodriguez *et al.*, 2006).

Another term of comparison used for evaluating the DTM's performances were the requirements for IGN's and Spot Image's Reference 3D®. The Reference 3D® is a 1arc second DEM extracted by means of automatic correlation from SPOT-5/HRS stereo data. Its specifications are given in Table 2 (Gachet and Favé, 2006).

Parameter	Specifications
DEM resolution	1arc second (~30m on the Equator; 21m at 45° of latitude)
Planimetric absolute accuracy	15m at 90% confidence level
Altimetric absolute accuracy	10m at 90% confidence level, for slopes lower than 20% 18m at 90% confidence level, for slopes included in 20% and 40% 30m at 90% confidence level, for slopes greater than 40%
Planimetric relative accuracy:	10 m at 90% confidence level
Altimetric relative accuracy	5m at 90% confidence level, for slopes lower than 20% 15m at 90% confidence level, for slopes included in 20% and 40% 28m at 90% confidence level, for slopes greater than 40%

Table 2. Reference 3D® specifications.

4. RESULTS AND DISCUSSION

4.1 High-resolution DTM generation

Four high-resolution Cartosat-1 DTMs were generated in the range of 2.5m - 10.0m. Because of the huge amount of data involved, the accuracy analysis of the high-resolution DTMs was performed on two subsets with different characteristics: i) a flat area with a dominant land cover of cultivated/crop fields and ii) a hilly area with an elevation range from 53m to 470m and a dominant forest land cover type. The subsets were selected as being representative samples of all the image content.

The best results were achieved using five GCPs (four in the corners and one in the middle of the image), regardless the resolution of the DTMs generated. On the other hand, a

significant difference was observed between the flat and hilly areas, the former being more accurate.

When comparing the Cartosat-1 high-resolution DTMs to the high precision ICPs, it was obtained a mean value of residuals (μ) between 0.29m (for the 2.5m, 7.5m and 10m grid cell size) and 0.37m (for the 5m grid cell size), a standard deviation (σ) between 1.62m (for the 10m grid cell size) and 1.81m (for the 5m grid cell size), a RMSE between 1.61m (for the 10m grid cell size) and 1.81m (for the 5m grid cell size) and a LE90 of 2.60m (for all the resolutions).

When comparing the Cartosat-1 high-resolution DTMs to the ADS40_DTM, for the flat terrain it was assessed a RMSE between 2.87m (for the 10m grid cell size) and 3.39m (for the 2.5m grid cell size) and a LE90 between 4.60m (for the 10m grid cell size) and 5.50m (for the 2.5m grid cell size), while for the hilly area a RMSE between 11.96 (for the 7.5m grid cell size) and 12.89 (for the 2.5m and 5m grid cell size) and a LE90 between 18.20 (for the 7.5m grid cell size) and 19.80 (for the 2.5m and 5m grid cell size). The overall accuracy was between 6.30m and 7.20m for RMSE and between 8.10m and 9.70m for LE90. Table 3 shows a summary of results.

When comparing the Cartosat-1 high-resolution DTMs to the Reference 3D[®] specifications, there is little difference between the DTMs generated at different resolution, and the Reference 3D[®]'s requirements are always fulfilled (Table 4).

Terrain's type	Resolution (m)	μ (m)	σ (m)	RMSE (m)	LE90 (m)
Flat	2.5	-1.11	3.20	3.39	5.50
	5.0	-1.08	3.02	3.20	5.20
	7.5	-1.07	2.83	3.02	4.90
	10.0	-1.07	2.66	2.87	4.60
Hilly	2.5	-0.55	12.88	12.89	19.80
	5.0	-0.59	12.87	12.89	19.80
	7.5	-0.42	11.95	11.96	18.20
	10.0	-0.55	12.56	12.58	19.30
Overall	2.5	-0.80	7.20	7.20	9.70
	5.0	-0.90	7.10	7.10	9.50
	7.5	-0.90	6.20	6.30	8.10
	10.0	-0.90	6.50	6.50	8.40

Table 3. Accuracy of the Cartosat-1 high-resolution DTMs.

4.2 Medium-resolution DTM generation

Starting from input data, a 25m resolution DTM was generated and its accuracy was validated both using a set of high precision ICPs extracted from the original C-SAP dataset and using a downsampled version of the ADS40_DTM.

The best medium-resolution DTM was obtained using five GCPs. The accuracy evaluation based on the ICPs led to the following results: $\mu=-0.02m$, $\sigma=1.68m$, $RMSE=1.65m$ and $LE90=2.37m$. On a global scale, the comparison of the medium-resolution Cartosat-1 DTM with the downsampled ADS40_DTM led to the following results: $\mu=-1.45m$, $\sigma=7.76m$, $RMSE=7.91m$ and $LE90=10.20m$.

Table 5 shows the influence of the GCPs (number and geometry) on the final Cartosat-1 image processing. Results have been compared to the ADS40_DTM downsampled at 25m resolution.

DTM resolution (m)	Slope range (%)	Reference 3D [®] requirements (LE90)	Cartosat-1 DTM (LE90)
2.5	0-20	10.00m	5.50m
	20-40	18.00m	17.20m
	>40	30.00m	21.90m
10	0-20	10.00m	5.20m
	20-40	18.00m	13.70m
	>40	30.00m	22.40m

Table 4. Accuracy of the Cartosat-1 high-resolution DTMs. Statistics on residuals (LE90) computed with respect to Reference 3D[®] requirements.

4.3 Low-resolution DTM generation

The investigation also tested the accuracy in the generation of low-resolution DTMs from Cartosat-1 data. In this case, results were tested also with respect to i) a set of high precision UCPs extracted from the original C-SAP dataset, ii) a downsampled version of the ADS40_DTM and iii) the NASA's SRTM, widely used in the remote sensing community.

With respect to the high precision ICPs, both Cartosat-1 and SRTM DTMs showed similar results: 2.64m RMSE and 2.67m RMSE, respectively for Cartosat-1 and SRTM, and 3.80m LE90 for both.

With respect to the downsampled ADS40_DTM, the Cartosat-1 DTM showed better results than the SRTM DTM. For the former it was observed a RMSE of 5.28m and a LE90 of 7.60m, while for the latter a RMSE of 6.50m and a LE90 of 10.00m.

As it was observed also for the Salon de Provence (France) test site, when comparing Cartosat-1 and SRTM low-resolution DTMs the former shows better overall accuracy (Gianinetta, 2008).

5. CONCLUSIONS

For the Mousanne les Alpilles test site it was fully investigated the potentialities and limits of the 2.5m panchromatic Cartosat-1 stereo images in generating DTMs using commercial off-the-shelf software, so from the point of view of a typical user.

For the high-resolution DTMs (in the range of 2.5m-10.0m), regardless the DTM's grid resolution, the investigation pointed out that in flat areas the accuracy is about 4-5 times better (about 3m RMSE and about 5m LE90) than that in hilly areas (about 12m RMSE and about 20m LE90). In any case, the accuracy of Cartosat-1 DTMs fulfilled the requirements of the Reference 3D[®].

For the medium-resolution DTM (25m), the overall accuracy of the Cartosat-1 DTM was about 8m RMSE and about 10m LE90.

Finally for the low-resolution DTM (90m), as it was observed also for the Salon de Provence (France) test site, the Cartosat-1

DTM performed better (7.60m LE90) than the SRTM (10m LE90) on the whole study area.

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GCPs nr.	GCPs' configuration	μ (m)	σ (m)	RMSE (m)	LE90 (m)
1		4.41	9.24	10.24	15.4
2		-1.34	9.29	9.39	13.2
2		-3.41	9.28	9.89	14.2
3		-3.76	7.76	8.62	11.5
3		8.62	8.29	11.96	16.9
3		2.31	8.57	8.86	11.3
4		-2.97	7.78	8.32	11.1
4		1.8	7.91	8.11	10.7
4		-1.51	7.86	8	10.3
5		-1.45	7.76	7.91	10.2
6		-2.94	7.73	8.27	11
7		-1.87	7.73	7.95	10.6
8		-2.07	7.73	8.01	10.7
9		-1.73	7.74	7.93	10.6

Table 5. Accuracy of the Cartosat-1 medium-resolution DTM.

