

CARTOSAT-1 STEREO IMAGERY: POTENTIALITIES ABOUT ORIENTATION, DSM EXTRACTION AND ORTHORECTIFICATION

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Commission I, WG I/5

KEY WORDS: Cartosat-1, stereo orientation, DSM extraction, accuracy assessment

ABSTRACT:

CARTOSAT-1 satellite was launched in May 2005; the optical sensor is configured with two pushbroom cameras, namely Aft and Fore, tilted in along track direction by -5° and $+26^\circ$, providing stereoscopic imagery in the same pass with a ground resolution of 2.5 m. Within the ISRO-ISPRS Cartosat Scientific Assessment Program (C-SAP), investigations were carried out on a stereopair belonging to the test field called TS-6, acquired on 8th June 2005 over the city of Rome, Italy ($30 \times 7.5 \text{ km}^2$), in order to test the sensor potentialities for DSM generation.

The stereo images were processed with PCI-OrthoEngine software, using a generic rigorous sensor model; the image orientation and the DSM geocoding were based on GCPs collected by GPS surveys with a mean 3D accuracy of 5-10 cm.

For the evaluation of the DSM accuracy, it was compared with the DSM generated from a block of 6 aerial photos (scale 1:9'000) over an area of about $3.5 \times 4 \text{ km}^2$.

An orientation with horizontal and vertical accuracy at sub-pixel level may be obtained with a “generic rigorous model”; as regards DSM extraction, an accuracy ranging from 1 to 2 pixel, depending on the feature of the land cover (urban zone, bare soil) is achievable with commercial image matchers.

1. INTRODUCTION

Cartosat-1 was launched on 5th May, 2005 at Satish Dhawan Space Centre (SDSC) SHAR, Sharikota, India's spaceport (Figure 1).

The satellite flies along a Sun-synchronous orbit at a mean altitude of 618 km, with an inclination of 97.87 degrees and a mean revolution period equal to 97.12 minutes.

The Sun-synchronous orbit provides imagery collection under near-constant illumination conditions and repetitive coverage of the same area in a specified interval.

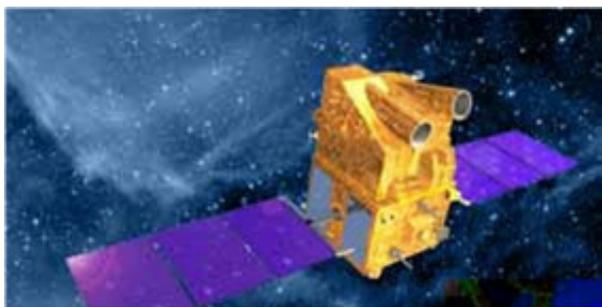


Figure 1. Cartosat-1 satellite

The Cartosat-1 sensor offers a across-track resolution of 2.5 m in panchromatic mode.

In addition the optical sensor is configured with two pushbroom cameras which are mounted such that one camera is looking at $+26^\circ$ (band F) and the other at -5° (band A) along the track. These two cameras provide stereoscopic image pairs in the same pass (Krishnaswamy et al., 2006).

The Institutes of Area di Geodesia e Geomatica - Sapienza Università di Roma, Eurimage S.p.A. and CyberCity AG joined as Investigators the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP), for the investigation of Cartosat-1 stereo imagery for DEM/DSM generation, 3D features extraction and orthophoto production (C-Sap, 2006). This paper reports the second part of the investigations carried out on the available stereo imagery (TS-6).

After a brief description of the available and used data, the results of images orientation with a generic rigorous model and the comparison between the DSMs are presented and discussed.

2. DATA

The data set of this investigation (TS-6) consisted of:

- a stereopair from Cartosat-1 satellite with corresponding metadata files;
- 43 ground points;
- DSM derived from a block of 6 aerial photos

In the next paragraphs the main data characteristics are described.

2.1 Cartosat-1 stereo scenes

The two stereo images were acquired on 8th June 2005 in the morning; the time interval between the two images is 53 sec. Each image is 12'000 x 3'000 pixel large, with a ground resolution of 2.5 m.

The imagery width is of 3'000 pixel because only 3'000 of 12'000 sensor detectors were active; the overlapping is almost 90%.

The scenes cover an area of approximately 30.0x7.5 km² over the city of Rome and suburbs, is characterized by a quite flat terrain with elevations ranging between 20 and 60 m (Figure 2); the morphology is mainly of urban type, with buildings of different heights, generally with no more than 6-8 floors (20-25 m).

The scenes were acquired in panchromatic mode with attitude angles (roll, pitch, yaw) close to zero and approximately equal for both of them; as already mentioned the stereo viewing is guaranteed (with a B/H ratio of about 0.6) by the sensor structure which is configured such that one camera scans the ground with off-nadir angle of +26° (forward image: band F) and the other with off-nadir angle of -5° (backward image: band A).

The metadata files contain information on the acquisition time, image location, mean attitude angles and sensor geometry (detectors looking angles), but no data about ephemeris.

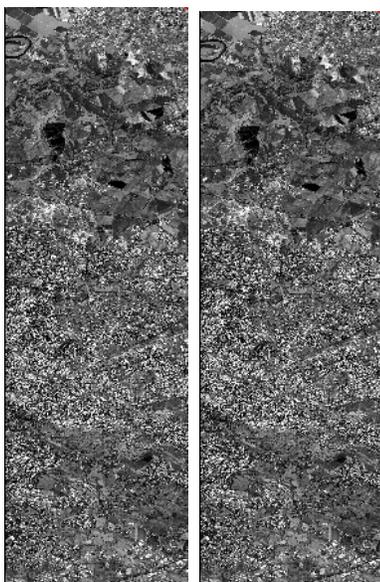


Figure 2. Cartosat-1 stereo scenes: band A (left) and band F (right)

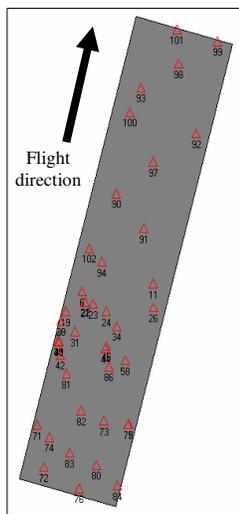


Figure 3. Distribution of the 43 ground points

2.2 Ground Control Points

For this investigation 43 ground points, well distributed over the whole area and suited for acting both as Ground Control Points – GCPs and as Check Points – CPs, were available. All these points were surveyed by geodetic class GPS surveys with 3D accuracy (RMSE) of 5-10 cm (Figure 3).

2.3 Reference DSM

The reference DSM has been extracted from a block of 6 aerial photos (scale 1:9'000, footprint: 14 cm), on an area of about 3.5 x 4 km² (Figure 4).

The two strips have an along track and an across track overlap of about 60% and 20% respectively.

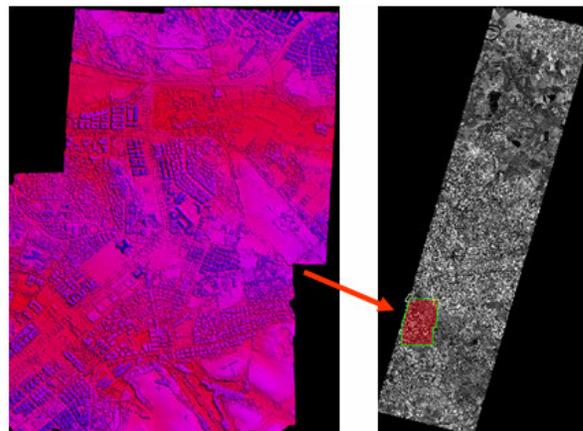


Figure 4. Reference DSM from aerial photos

Unfortunately the 6 aerial photos available for the reference DSM extraction cover a small area of the satellite imagery (about 6 % only), characterized by a wide variety of urban environments (tall and low buildings, parks with high trees and bare soil).

3. IMAGERY ORIENTATION

The PCI-OrthoEngine software was used to orient the stereopair with an approach based on a so called “generic rigorous model” (Dowman and Michalis, 2003).

It is well known that a rigorous model should describe the physical properties of the sensor and its image acquisition mode; it is an approach mainly photogrammetric (collinearity equations) accounting for the satellite position, the sensor attitude and characteristics, and an eventual final cartographic transformation. (Crespi, 2006/3)

The used version of this software (v. 10.0) implements the well-known Toutin's rigorous model for several high-resolution satellites including IKONOS, Quickbird, EROS A and many others, but the sensor model of Cartosat-1 is not yet included (PCI, 2006).

However it's possible to create an orbital model for Cartosat-1 images using a generic rigorous model that necessitates manually entering approximate parameters about the satellite image and orbit data: across and along track angle, IFOV, mean satellite altitude, orbital period, orbit eccentricity and inclination, pixel spacing and scene centre. The corresponding values for Cartosat-1 were available in the metadata files.

After the block adjustment, it is possible to analyze the results of the stereo images orientation in terms of residuals both on GCPs and CPs.

3.1 Results of imagery orientation

In this paragraph the residuals of CPs for the stereo scenes are reported (Table 5, Figure 6) and discussed. Several tests have been carried out using a different number of GCPs, always homogeneously distributed, in order to find the lowest number of

GCPs to obtain the accuracy (RMSE on North and East CPs residuals) assessment.

Overall a horizontal and vertical accuracy at sub-pixel level is achievable. The accuracy stabilizes with a GCPs number between 21 and 25.

STEREO ORIENTATION - RIGOROUS MODEL				
GCP	GCP + CP	RMSE		
		E (m)	N (m)	H (m)
9	9 + 34	1.81	1.76	2.91
12	12 + 31	2.01	1.70	2.27
15	15 + 28	2.01	1.69	2.14
18	18 + 25	2.03	1.64	1.93
21	21 + 22	1.93	1.40	1.98
25	25 + 18	2.02	1.46	1.77
29	29 + 14	2.04	1.46	1.97
34	34 + 9	2.01	1.41	1.57

Table 5. RMSE of the CPs residuals with 3D orientation

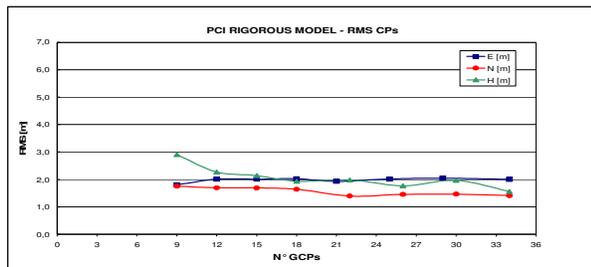


Figure 6. Graph of the RMSE of the CPs residuals with 3D orientation

4. DSM GENERATION

DEM and DSM generation from high resolution satellite imagery is a hot topic for some years (Toutin, 2001; Toutin and Cheng, 2001; Toutin, 2004/1; Toutin, T., 2004/2).

In our experiment the DSM was generated at the resolution of 2 pixel (5 m) using for the orientation 21 GCPs well distributed on the whole images.

A quantitative evaluation of the DSM was carried out by the comparison with the reference DSM generated from the aerial photos, over three zones with different characteristics: one urban zone and 2 open zones.

We computed the 3D differences (Cartosat-1 DSM minus aerial photos DSM), by Geomatic Studio 9 software, between the interpolated DSM and the reference DSM, showing the results of the raw computations, without any a posteriori manual editing procedure. In Table 7 the results obtained are reported.

Overall the accuracy (RMSE) of the generated DSM is at the level of 1-2 pixel, better for open than for urban zones as likely expected. Nevertheless it is mandatory to point out some differences.

In fact for the test relative to the urban zone, where usually there are streets in very dense residential zones, the high percentage of buildings tends to raise DSM heights over the road level (positive errors) (Crespi et al. 2006/2) and, in the same time, to smooth the building edges (negative errors) (Figure 8).

STATISTICS	URBAN ZONE	OPEN ZONE 1	OPEN ZONE 2
POINTS	9515	26162	36159
AVERAGE [m]	2.67	-2.93	-0.65
ST.DEV [m]	4.81	3.77	3.24
RMSE [m]	5.50	4.77	3.30
MIN:	-22.89	-29.90	-25.76
MAX:	29.94	22.32	23.75

Table 7. Results of DSM accuracy over urban and open zones

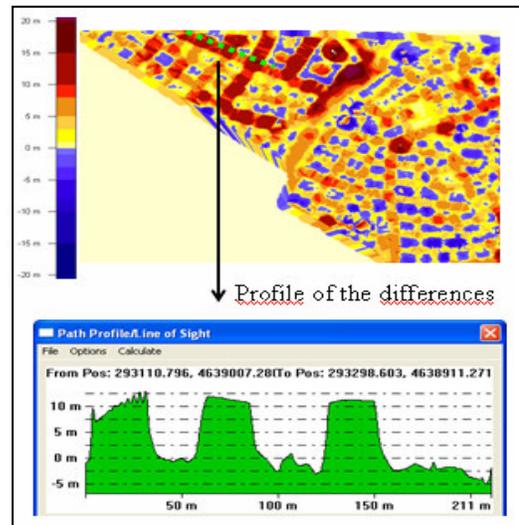


Figure 8. Example of a profile of the differences

As regards the tests over the open zones, it has to be evidenced a negative value of the average, due to the negative residuals localized in correspondence of tree-lined zones; this bias is likely to be caused again by the mentioned smoothing effect, even if further insights will be developed since almost all over the open areas seems to be evident a negative bias (Figure 9).

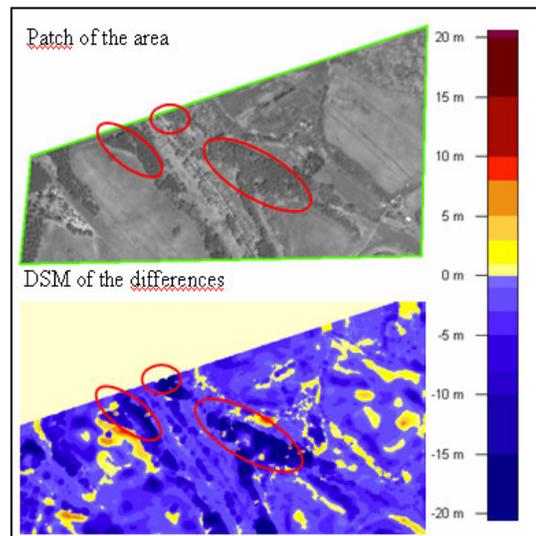


Figure 9. Negative errors in correspondence of the tree-lines

5. DISCUSSIONS AND CONCLUSIONS

The Institutes of Area di Geodesia e Geomatica, Eurimage S.p.A. and CyberCity AG are participating as Investigators in the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP), in order to investigate the potentiality of Cartosat-1 stereo scenes.

During this first research period, these Institutes were involved in the processing of the dataset associated to TS-6 (Rome, Italy); in particular, DEM/DSMs generation, 3D features extraction for city modeling and orthophotos generation were investigated (Crespi et al. 2006/1, 2006/2).

The results, representing an update of those discussed in (Crespi et al. 2006/1), showed that a good orientation with horizontal and vertical accuracy at sub-pixel level may be obtained with a "generic rigorous model" too. It has to be underlined that these results may suffer for the singularity of the considered stereo pair, which is quite narrow due to the fact that only 3'000 of 12'000 sensor detectors were active.

Results about DSM extraction indicate that an accuracy (RMSE) of 1-2 pixel may be achieved with commercial image matchers, even if significant biases are evidenced over urban zones and with isolate tree-lines over bare soil.

Future research prospects will be focused on:

- test on larger areas, when new complete scenes will be available in the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP)
- additional investigations on the DSM generation and 3D feature extraction, with manual measurement of breaklines and masspoints, image matching enhancement by suitable pre-filtering and use of more refined image matchers (Fraser et al., 2002; Gruen and Zhang, 2002; Kocaman et al. 2006; Poli, 2006; Ulm, 2003)
- studies on image quality, which can remarkably affect the achievable geometric accuracy both in orientation, DSM extraction and final orthophoto production (Zhang, 2005)

Finally, we are designing an original rigorous model for stereo orientation of Cartosat-1 imagery and to insert it in the software SISAR (Crespi et al., 2006/3) implemented at the Area di Geodesia e Geomatica -Sapienza Università di Roma.

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ACKNOWLEDGEMENTS

The authors would like to thank very much Dr. Nandakumar, for the coordination of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) and for accepting our Institutes as Investigators.