

# ORIENTATION, ORTHORECTIFICATION, DSM EXTRACTION AND 3D CITY MODELING BY CARTOSAT-1 STEREO IMAGERY: FIRST RESULTS OF A TEST OVER ROME

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## ABSTRACT:

CARTOSAT-1, launched in May 2005, is basically a stereo mission; in fact it is equipped with two cameras onboard, namely Aft and Fore, tilted in along track by  $-5^\circ$  and  $+26^\circ$ , allowing the acquisition of stereo data for every scene with a resolution of 2.5 m.

The Institutes of Area di Geodesia e Geomatica - Università di Roma “La Sapienza”, Eurimage S.p.A. and CyberCity AG participated at the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP), in order to investigate the DSM generation from Cartosat-1 stereo scenes.

This paper describes the work carried out on the stereopair belongin to the test field called TS-8 (Rome, Italy), acquired on 8th June 2005 over the city of Rome, Italy. The stereo images related to the test field were processed with several commercial software (PCI-OrthoEngine, ERDAS, CyberCity-Modeler –CCM-), in order to perform preliminary tests on the sensor potentialities for geomatic applications. The processing included the sensor orientation, DSM generation, orthoimage production and 3D features extraction,.

For the orientation of Cartosat-1 imagery, two alternative approaches have been used: a generic rigorous sensor model , implemented in PCI-OrthoEngine, and a rational polynomial coefficients model (RPC), available in PCI-OrthoEngine, ERDAS and CCM.

For the evaluation of the DSM accuracy, the DSMs extracted were compared with the heights of several buildings and points on road axis derived from a large scale 3D map (1:2’000); an accuracy (RMSE) between 1 and 1.5 pixel (about 3 m) was achieved both on building heights and on road axis. Secondly, to evaluate the potentials of the images for 3D features extraction, some buildings were modelled semi-automatically in CCM and again compared with the 1:2’000 3D map, achieving an accuracy around 4 m. The third focused item, regarded the evaluation of the orthoimage accuracy, which was estimated by a 2D comparison with the same large scale 3D map; it was showed that it is possible to obtain a horizontal accuracy better then 1 pixel.

## 1. INTRODUCTION

Cartosat-1 was launched on 5<sup>th</sup> 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.

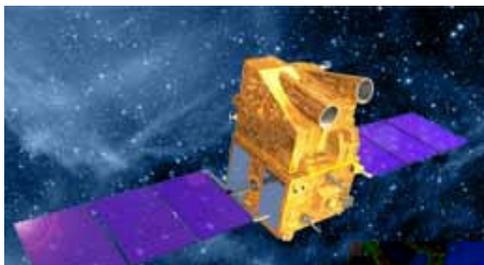


Figure 1. Cartosat-1 satellite

The Cartosat-1 sensor offers high resolution in across-track direction with to 2.5 m resolution 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  $-5^\circ$  (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 - Università di Roma “La Sapienza”, 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 preliminary investigations carried out from June to August 2006, as soon as the stereo imagery of the TS-8 (Rome, Italy) were available. After a brief description of the available and used data, the results of images orientation with two different methods (generic rigorous model and RPC model), comparison between the DSMs and orthophotos generated with a large scale (1:2’000) 3D map and 3D features extraction are presented and discussed.

## 2. DATA

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

- a stereopair from Cartosat-1 satellite with corresponding metadata files;
- monographs of 48 ground points;

- Rome Municipality official large scale (1:2'000) 3D map;
- DEM derived from contour lines and spot heights of the Rome Municipality 3D map

In the next paragraphs the main data characteristics are described.

### 2.1 Cartosat-1 stereo scenes

The two stereo images were acquired on 8<sup>th</sup> 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 3000 pixel because only 3000 of 12000 sensor detectors were active; the overlapping is almost 90% (Figure 2).

The scenes cover an area of approximately 30.0x7.5 km<sup>2</sup> over the city of Rome and suburbs. Anyway the investigation has been focused on a smaller area (about 5.0x7.5 km<sup>2</sup>) where GCPs were already available.

The area is characterized by a quite flat terrain with elevations ranging between 20 and 60 m; 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: BANDF) and the other with off-nadir angle of -5° (backward image: BANDA).

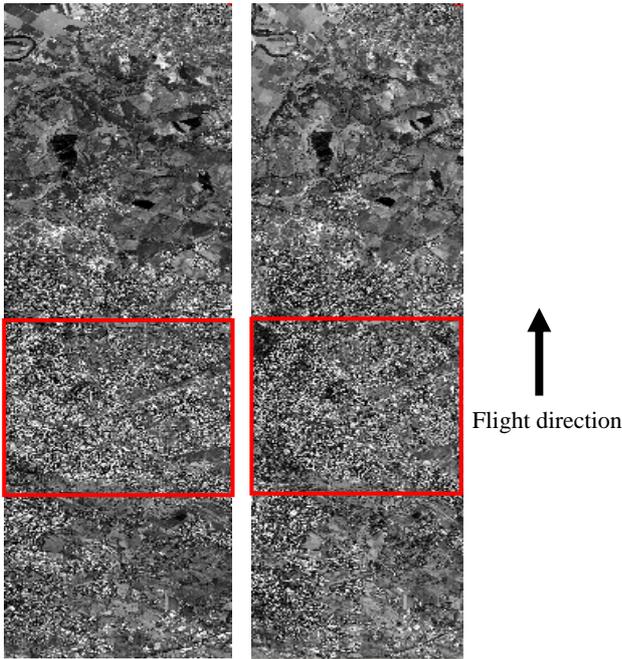


Figure 2. Cartosat-1 stereo scenes: band A (left) and band F (right); red rectangles border the considered area

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.

### 2.2 Ground Control Points

For this investigation 48 ground points, suited for acting both as Ground Control Points – GCPs and as Check Points – CPs),

were available. Their characteristics and coordinates were reported in proper monographs already available, but only 21 have been identified in the Cartosat-1 images. All these points were surveyed by geodetic class GPS surveys with 3D accuracy (RMSE) of 5-10 cm.

The final point distribution is shown in Figure 3. The working area is well covered by GCPs, with few lacks in the NW and SE.

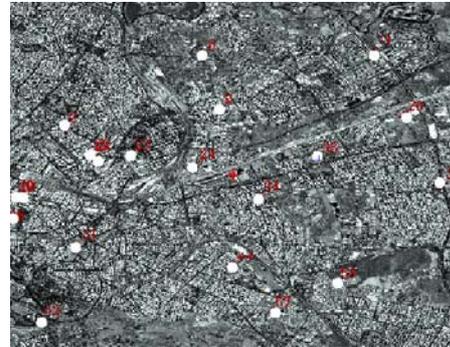


Figure 3. Distribution of the identified 21 ground points (white)

### 2.3 Reference 3D map and reference DEM

The Rome Municipality official large scale (1:2'000) 3D map, used as reference, was provided by Cartesia S.p.A in vector format; it includes the contour lines, spot heights, buildings and roads (Figure 4) in different layers. The map has 2-sigma tolerances of 60 cm (horizontal), 50/90 cm (vertical: spot heights/contour lines) and 80 cm (building heights).

The reference DEM has been derived, in raster format, from contour lines and spot heights of the same large scale 3D map, using PCI-OrthoEngine software. The height accuracy (RMSE) is 50 cm (Figure 5).



Figure 4. Particular of reference 3D map (buildings and roads)

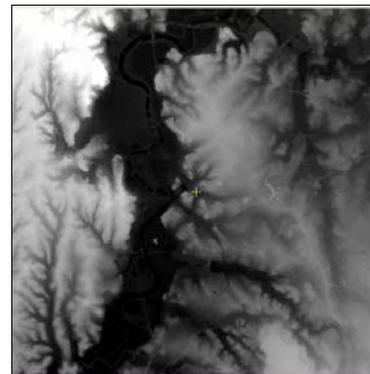


Figure 5. Reference DEM

### 3. IMAGERY ORIENTATION

For the orientation of the imagery three commercial software (PCI-OrthoEngine, ERDAS, CyberCity-Modeler –CCM-) and two approaches, based on rigorous model and rational function model (RPC) respectively, were adopted.

The rigorous model describes the physical properties of the sensor and its image acquisition mode; it is an approach mainly photogrammetric (collinearity equations) and considers the satellite position, the sensor attitude and characteristics, and an eventual final cartographic transformation.

The alternative approach is based on the RPC model, where the link between image and ground coordinates is described by a simple mathematical relation that does not consider the geometrical-physical process of image generation. The RPC model relates image coordinates (row and column) to ground coordinates by two polynomial ratio, with possible additional corrections; polynomial coefficients are provided into the metadata file associated to each image, whilst eventual corrections are estimated from GCPs (Di et al., 2003).

For the stereo scenes orientation both approaches have been applied, using a subset of the available 21 ground points as GCPs and the remaining as CPs.

In the next paragraphs the software and the algorithms used for the orientation will be described and the results reported.

#### 3.1 PCI-OrthoEngine: generic rigorous model and RPC model (Order 0 and 1)

The PCI-OrthoEngine software was used to orient the stereopair with a generic rigorous model and with RPC model (order 0 and 1).

The software implements the well-known Toutin's rigorous model for several high-resolution satellites including IKONOS, Quickbird, EROS A and many others; 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.

PCI-OrthoEngine implements also RPC model with correction of order 0 (translation) and order 1 (affine transformation), but

in this case the math model is computed for each image separately, so that the results of each single image orientation (not of the 3D stereo orientation) are supplied only; these results are not considered here since are not comparable to those stemming from the other software.

#### 3.2 ERDAS: RPC model (Order 0 and 1)

The ERDAS software was used to orient the stereopair only with RPC model with correction of order 0 (translation) and order 1 (affine transformation), because any rigorous model is not available. In this case the software provides the results of a 3D stereo orientation. (Leica, 2005)

#### 3.3 CyberCity-Modeler (CCM): RPC model (Order 1)

CyberCity-Modeler (CCM) is a modular photogrammetric software for the processing of aerial and satellite stereo images for the generation of 3D building models (Ulm, 2003). One of its modules is dedicated to the orientation of satellite images, DSM and orthophoto generation (Poli, 2006). The approach for the image orientation is based on the RPC model of order 1; it is possible to analyze the results of the stereo images orientation in terms of RMSE of GCPs and CPs.

#### 3.4 Results of imagery orientations

In this paragraph the results of the stereo scenes orientation with the three software and the two models are reported (Table 1). 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.

The results obtained with rigorous model and the RPC approaches are very similar. Considering the image resolution, the differences obtained by the different software are not significant. The accuracy stabilizes between 12 and 15 GCPs.

In general an horizontal accuracy at sub-pixel level is achievable, whilst vertical accuracy is approximately the half (RMSE is double), ranging between 1 and 2 pixel. On the contrary, RPC model with correction of order 0 (ERDAS) gives unsatisfactory results. It might be mentioned that in none of the software used blunder detection on the image coordinates is applied. For this reason measurement errors might be present in the orientation procedure.

GCPs + CPs ( <i>m</i> )	PCI-OrthoEngine. Rigorous model			ERDAS. RPC Order 0			ERDAS. RPC Order 1			CCM. RPC Order 1		
	<i>E</i>	<i>N</i>	<i>h</i>	<i>E</i>	<i>N</i>	<i>h</i>	<i>E</i>	<i>N</i>	<i>h</i>	<i>E</i>	<i>N</i>	<i>h</i>
9+12	1.68	3.77	3.46	4.85	1.92	3.74	1.58	2.50	3.83	1.72	2.05	3.17
12+9	1.45	2.78	3.96	4.63	1.61	4.25	1.42	2.15	4.22	1.56	1.91	3.62
15+6	1.65	2.26	4.05	5.35	1.19	4.23	1.52	1.86	4.25	1.59	1.19	4.08

Table 1. Results of 3D orientation: PCI\_OrthoEngine-Rigorous model, ERDAS-RPC orders 0 and 1, CCM-RPC order 1

### 4. DSMs GENERATION

Three DSMs have been generated using the two orientation methods described in Section 3. In particular, all these products were obtained at the resolution of 2 pixel (5 m), using for the orientation all the available GCPs (21) and the model that for each software supplied the best orientation results:

- DSM#1 has been generated with PCI-OrthoEngine software and the generic rigorous model;

- DSM#2 has been generated with ERDAS software and the RPC model with correction of order 1;
- DSM#3 has been generated with CCM software and the RPC model with correction of order 1

In Figure 7 the visualization of the generated DSM by PCI-OrthoEngine is shown.

After the DSMs generation, the accuracy tests have been performed to examine three different aspects:

- evaluation of the DSM accuracy by the comparison with the heights of several buildings and points on road axis derived from the reference 3D map;
- evaluation of the intrinsic precision of DSM extraction over very regular horizontal surfaces

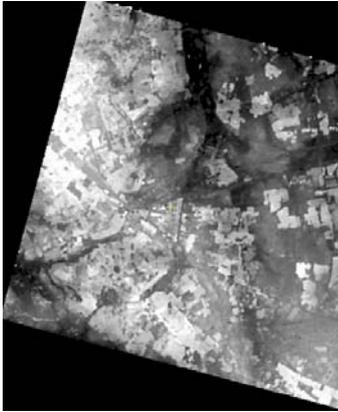


Figure 7. DSM generated by PCI-OrthoEngine software

The comparison between the DSMs extracted and the reference DEM does not make sense, because the two products describe different surfaces. Therefore, detailed comparisons with the heights of 44 very regular and well visible buildings and 200 points on road axes, derived from the reference 3D map was preferred.

It has to be underlined that the test area regards completely a part of the urban area of Rome, so that the high percentage of buildings tends to raise DSM heights over the road level (Crespi et al. 2006/1) and, in the same time, to smooth the building edges (Figure 8).

Therefore, for the evaluation of a building height, the comparison was performed on an area of the DSM smaller than the corresponding building area, introducing a buffer; the aim of this approach is to limit the influence by the errors of the automatic DSM generation algorithm.

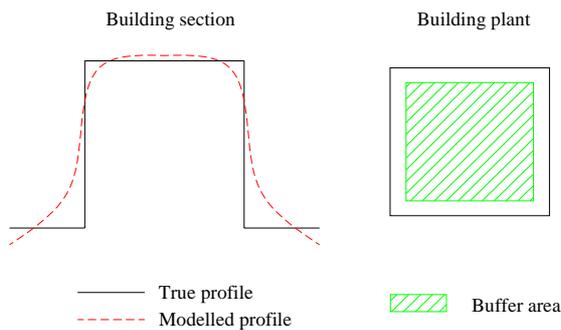


Figure 8. Modeling problems in building heights interpolation and buffer area

At this moment, these comparisons were carried out on DSMs extracted by PCI-OrthoEngine and ERDAS software; in Table 2 the results obtained are reported. The accuracy (RMSE) of the generated DSMs are approximately the same for the two software, at the level of 2.5-3 m both for buildings and for road axes. Very few outliers were identified, as testified by quite close values of average and median. Positive bias for PCI-OrthoEngine over buildings and for ERDAS over roads have to be investigated significantly enlarging the samples.

A successive investigation was performed regarding the “intrinsic precision”, that is what it is supposed to be the highest

achievable precision of DSM generation; very regular and approximately horizontal surfaces (quite common in an urban environment, like squares or parking area) are suited to this purpose (Crespi et al. 2006/1). Two small flat area (Park1: 65x55 m<sup>2</sup>, Park2: 40x30 m<sup>2</sup>), relative to two landing-strip, surrounded by bare soil (in order to avoid an eventual systematic effect induced by buildings) were chosen.

	N° of buildings: 44		N° of road pts: 200	
Statistics (m)	DSM#1 PCI	DSM#2 ERDAS	DSM#1 PCI	DSM#2 ERDAS
<b>AVERAGE</b>	-0.12	<b>1.90</b>	<b>1.16</b>	0.53
<b>ST. DEV.</b>	2.50	2.12	2.77	2.07
<b>RMSE</b>	<b>2.50</b>	<b>2.85</b>	<b>3.00</b>	<b>2.13</b>
<b>MEDIAN</b>	-0.48	2.00	1.13	0.34
<b>MAD</b>	2.32	2.04	2.37	1.41
<b>MIN</b>	-5.24	-4.91	-7.33	-4.94
<b>MAX</b>	5.21	6.77	13.78	10.31

Table 2. Results of DSMs accuracy over buildings and road axes points

At this moment, these comparisons were carried out on DSMs extracted by PCI-OrthoEngine and ERDAS software. In Table 11 the results obtained are reported: the “intrinsic precision” resulted at the level of 0.3-0.4 m, slightly better for ERDAS, but also in this case further more extended tests are required.

	Park1		Park2	
Statistics (m)	DSM#1 PCI	DSM#2 ERDAS	DSM#1 PCI	DSM#2 ERDAS
<b>ST. DEV.</b>	0.48	0.38	0.48	0.34

Table 3. Results about “intrinsic precision” of DMSs

It has to be underlined that the 2 pixel DSM “intrinsic precision” provides also an indication about the accuracy requirements for GCP positions if the full potentiality of 3D feature extraction has to be exploited (e.g. in city modeling), hypothesizing all DSM generation biases may be corrected: roughly, 3D GCPs accuracy should not be worse than 1/3 of the “intrinsic precision”, that is of 0.10-0.15 m.

## 5. 3D FEATURES EXTRACTION

Besides the generation of DEM/DSM, a relevant application of the Cartosat-1 stereo scenes could be the 3D features extraction, which is quite useful for the 3D city modeling and, generally, for the updating of urban/suburban databases (especially buildings and roads network). For these purposes, specific tests with the original CCM software by CyberCity were performed. The test was carried out on a set of 12 buildings. Using a reality-based semiautomatic photogrammetric approach, the relevant roof points are first measured three-dimensionally in a photogrammetric station following specific rules, then they are imported as a point cloud and automatically fitted with roof faces. For common types of roof that follow geometric constraints like right angles and parallel lines, intelligent measurement rules were developed to reduce the number of points that are required to be measured to create an object. The vertical building walls extrude from the intersection of the roof polygons with the DTM. More details about CyberCity-Modeler are described in (Ulm, 2003). CCM has already been

successfully applied for the extraction of 3D buildings from very high resolution satellite sensors (Kocaman et al., 2006). In case of Cartosat-1, due to the ground resolution of 2.5m, it is possible to extract only low detailed block models. The building heights were compared with those of the reference 3D map while the heights of the road axis points were compared to the reference DEM (Table 4).

The results evidences an accuracy (RMSE) slightly worse than 4 m, which is satisfying considering the low image resolution and the vertical accuracy achieved in the orientation, which is approximately at the same level (RMSE around 4 m, Table 1). A 3D representation of the buildings is shown in Figure 9.

Statistics (m)	N° of buildings: 12
AVERAGE	2.06
ST. DEV.	3.59
RMSE	4.14
MAD	3.29
MEDIAN	2.20
MIN	-6.28
MAX	8.23

Table 4. Statistics of the comparison between 3D building models extracted in the CARTOSAT-1 images with CyberCity-Modeler and the Cartesia database.

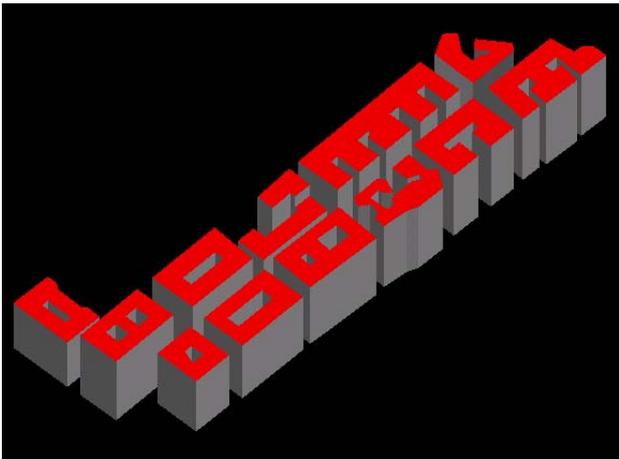


Figure 9. 3D building models semi-automatically extracted in Cartosat-1 images with CyberCity-Modeler.

## 6. ORTHOPHOTO GENERATION

Using the three DSMs extracted and the same orientation models (generic rigorous model for PCI-OrthoEngine software and RPC model of order 1 for ERDAS and CCM software) three orthoimages were generated from the scene BANDA, which is the most nadiral.

To evaluate the horizontal accuracy of the products obtained, a comparison with the reference 3D map was carried out.

The same 50 buildings used for the evaluation of DSMs accuracy were singled out on the orthophotos and vectorized. From the reference large scale 3D map the same 50 buildings were reduced to a 2D polygons.

The comparison between the correspondent polygons was performed calculating:

- the difference of the barycenters, as  $\Delta N$  and  $\Delta E$  (Figure 13), in order to highlight possible local georeferencing bias (Table 14);
- the mean discrepancy of the corresponding polygons, as  $\Delta S$  (Figure 13), considering the residual areas derived by the intersection of them (Table 15).

The expression of  $\Delta S$  is:

$$\Delta S = \sum_i \frac{\Delta A_i}{P_{ref}} \quad (1)$$

where  $\Delta A_i$  is the  $i$ -th residual area derived by the intersection of the polygons and  $P_{ref}$  is the perimeter of the reference polygon.

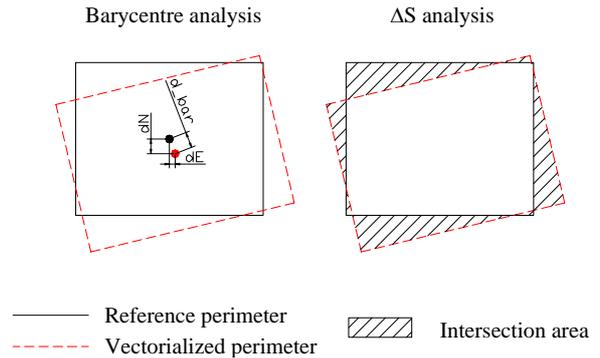


Figure 13. Corresponding 2D polygons comparison

Analyzing the results, it can be observed that PCI-OrthoEngine seems perform better than ERDAS. As regards PCI-OrthoEngine results, no significant georeferencing bias are present; moreover, as concern the mean discrepancies, their average value over the considered sample is less than 1/2 pixel and for the largest part they are within 1 pixel; overall, it seems possible to produce orthophotos with accuracy compatible to 1:10000 scale. As regards ERDAS results further investigation are required.

Statistics (m)	DSM#1 PCI		DSM#2 ERDAS	
	dE	dN	dE	dN
AVERAGE	0.24	0.24	-0.89	-1.76
ST. DEV.	0.74	1.56	1.36	1.69
MIN	-2.09	-3.13	-3.59	-4.58
MAX	1.26	3.82	2.33	1.72

Table 14. Results of the barycenters difference

Statistics (m)	DSM#1 PCI	DSM#2 ERDAS
	dS	dS
AVERAGE	1.19	1.96
ST. DEV.	0.40	0.70
MIN	0.57	0.66
MAX	2.75	3.18

Table 15. Results of mean discrepancy

## 7. 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, started about three months ago with the release of the imagery regarding some test sites (June 2006), 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.

The results showed that a quite good orientation may be obtained with RPC supplied in the metadata; moreover an accuracy (RMSE) of 2-3 m may be achieved in DSM extraction, at least over well visible buildings and roads.

The tests on orthoimages, generated with the DSMs previously extracted, showed that it is possible to obtain a planimetric accuracy better than 1 pixel (2.5 m). In addition, promising results (accuracy around 4 m) from low-detailed 3D feature extraction have been achieved.

Overall, the good results obtained in these preliminary tests seem open wide applications for Cartosat-1 imagery as concerns DSMs and orthoimages generation and 3D feature extraction. Future tests will include:

- Acquisition of new ground information and processing of Cartosat-1 images for all the area covered by the stereopair
- Blunder detection during the image orientation, generation of new DSM with new orientation parameters and relative tests
- Additional investigations on the DSM generation, with manual measurement of breaklines and masspoints, when necessary
- Analysis of additional 2D features (buildings and roads)
- Additional 3D features extraction with commercial software

In addition, we plan to develop an original rigorous model for stereo orientation of Cartosat-1 imagery and to insert it in the software SISAR (Crespi et al., 2006/2) implemented at the Area di Geodesia e Geomatica-Università di Roma "La Sapienza".

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