Evaluation of Cartosat-I Stereo Data of Rome

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ABSTRACT:

The scope of the work is to perform the stereo restitution of Cartosat-I data by refining the raw Rational Polynomial Coefficients (RPCs) for determining the (a) optimal requirement of control points, (b) geometric accuracy in plan and height, (c) accuracy of the Digital Elevation Model (DEM), and (d) adequacy of the resulting orthoimage for the purpose of topographic mapping. The data set obtained for the study (TS6: Rome, Italy) contains one stereo pair, 50 Control points and a reference Digital Terrain Model (DTM). With this product, the RPCs of third degree are provided in lieu of sensor and satellite parameters. These vendor-side RPCs are sensor-derived and terrain-independent. They require refinement at scene/block level for attaining mapping accuracy. The *user-side RPC refinement* model is adapted in this exercise. The reference frame adapted is WGS-84, UTM, and orthometric heights. The results demonstrate the RPCs could be refined to mapping accuracy standards using one GCP upwards. The DEM obtained through automatic matching needs to be reduced to bald-earth prior to comparing it with the reference elevations. Extraction of open areas for the purpose of DEM comparison is accomplished through filtering based on slope criterion. For orthorectification, the near-nadir image of AFT camera is used.

INTRODUCTION

Cartosat-I, launched in May 2005, has two cameras to collect stereo data at better than 2.5m resolution: one near-nadir-looking and the other forward-looking. A single stereo pair covers a ground area of 800 square kilometers approximately. The two stereo components, intuitively labeled AFT and FORE images to indicate the look direction, are designed to produce digital elevation models (DEMs). The data from on-board instruments like GPS and improvised star sensor are used to generate terrain-independent Rational Function Model (RFM).

Relevant Mission parameters are recapitulated here:

+ Flying Height: 618 km
+ Physical Pixel Dimension: 7 micron
+ Imaging Scale: 1:3,50,000
+ Field of View: ±1.30 deg
+ Stereo: in track ($+26^{\circ}$ and -5°)
+ Twin camera, capable to maneuver roll and pitch
+ Revisit: 5 days
+ Foot print: < 2.5 m in panchromatic providing a swath of 30km near equator
+ Position estimate of satellite: 50m (3σ)

Height Sensitivity of the Mission

With a ground sampling distance (GSD) better than 2.5m and convergence angle between the two cameras being fixed 31 deg, the mission is designed to generate stereo with a height sensitivity (defined as the change in elevation associated with a pixel) of 4m.

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The benchmarking studies are undertaken to verify this aspect primarily at two stages(a) triangulation through the use of independent check points (ICPs) (b) DEM level using the reference data.

THE DATA DESCRIPTION

Stereo Data described by the Path 0170-Row 206 is acquired on June 08, '05 over Rome, Italy. The relief of the site is plain with a maximum height around 80m. The texture comprised of built-up and open lands. The overlap between the stereo components is 97.5%. The scene sizes are 12000 lines and 3000 pixels each; imaged during the 508th orbit of the satellite. The Product code is SRPC00GOJ.

The characteristics of RPCs

Rational Function Model, provided in the form of Orthokit, enables the user to directly relate the image/stereo-model to object space, without the knowledge of the imaging system. With this product, users are provided with third degree polynomial coefficients in lieu of sensor and satellite parameters. Such vendor-side RPCs are sensor-derived and terrain-independent. They require refinement at scene/block level for attaining mapping accuracy by introducing GCPs. The model adapted in this exercise is categorized as *"terrain-dependent model scenario; user-side RPC refinement"*. For comprehensive treatment on this topic (Tao and Hu, 2001) may be referred.

Control Data

50 GCPs, with sketches and well-marked on EROS-A1 satellite chips, are provided. All the points are considered sub-metre

accurate. Majority of the points lie outside the stereo coverage. Out of the remaining, only 9 sharp points which are unambiguously seen in both FORE and AFT images and lying on the terrain are selected. Expectedly, a few more points could be seen in AFT image, by virtue of lesser obliquity of imaging. As seen in Fig 1, the control points support the model only in the middle.

Reference DEMs

DEM 1: Bare-earth DEM of 1m cell resolution is provided by the C-SAP Programme. This is referred to as 1m-DEM hereafter. This contained 11981 columns and 12021 rows with bounding coordinates of (285808, 4646733) and (297789, 4634712). This falls in the UTM Zone 33 extents.

DEM 2: Research grade DEM generated from C-band SRTM with 3-arc second cell size is used. This is referred to as SRTM DEM hereafter. These are surface elevations referred to WGS84 in plan. The DEM common to entire Cartosat-I model area is downloaded through ftp {site}.

To be consistent with the notation, DEM extracted from Cartosat-I will be referred to as CartoDEM.

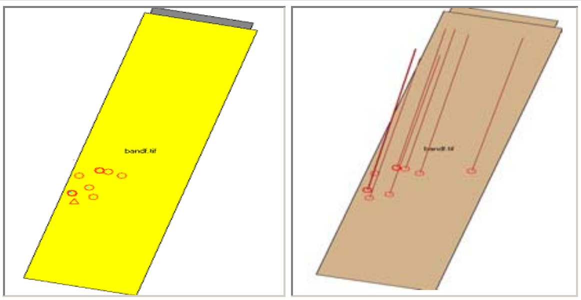

Figure 1a. Distribution of GCPs Figure 1b. residuals (magnified 100 times) at the check points in no-GCP situation.

EVALUATION STRATEGY

Stereo triangulation of Cartosat-I is performed for determining the following:

+ Geometric accuracy in plan and height
+ Minimum requirement of control points
+ Analysis with different control configurations
+ DEM generation and evaluation
+ Orthorectification and evaluation

Design of Tests

The possible options of modeling range from bias-compensation to well-supported configuration. However, cases 1 and 2 will be critically examined, considering that GCPs are a scarce and expensive commodity.

Case 1	No controls used
Case 2	One control point in the middle of the stereo model
Case 3	Two GCPs
Case 4	Three GCPs
Case 5	Four GCPs

Table 1. Control Configuration for stereo Triangulation

Leica Photogrammetry Suite V9.0 running on Windows is used for data processing

Restitution Results

From the triangulation results (plotted listed in Figure 2), it is evident that the raw RPCs suffer from positional bias. Figure 3 further illustrates these inaccuracies in each image in terms of pixels for the check points.

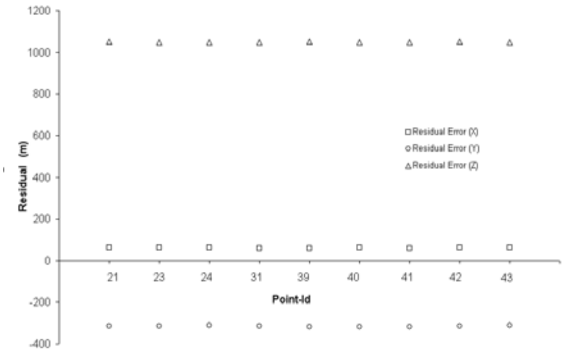

Figure 2. The error plot in X,Y,Z in no-GCP scenario

Raw accuracy of the stereo model happens to be 60.9m in X and 314.6m in Y. This relatively oriented model has a height error of 1049m.This is determined by using all 9 points as check and without any RPC refinement. The error vectors plotted in Figure 1b clearly show the systematic offsets in the raw scene location determination. The vectors demonstrate the error is dominant in along the satellite track, and this may be construed as the bias in pitch estimate.

To minimize this effect, GCPs are introduced to refine RPCs. The minimum configuration of one GCP is tried first and subsequently more GCPs are added .

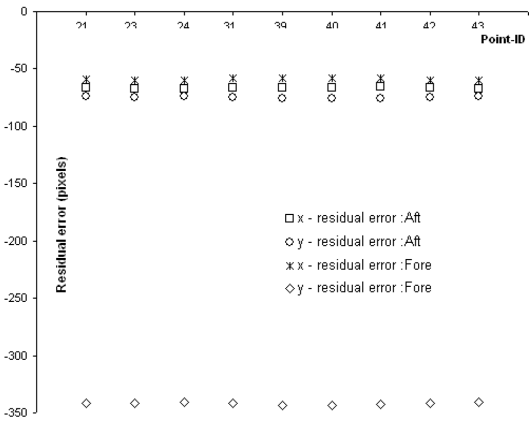

Figure 3. Image residuals in Aft and Fore images in no-GCP situation

The RMS errors at independent Check Points in X-direction ranged between 2.08 to 2.65m; in Y-direction between 2.08 to 2.37m; and in Z-direction between 1.71 and 2.53m. The maximum error is an important measure for assessing the triangulation accuracy. In X and Y, the absolute maximum error is 2.84m. More importantly, it is observed that Z-error never exceeded 3m.

GCPs (with Check points in brackets)	Model Error (RMSE in m) X	Y	Z	Check Point Error (RMSE in m) X	Y	Z
0 (9)	-	-	-	60.9	314	1049
1 (8)	0	0	0	2.57	2.08	2.53
2 (7)	0.61	0.29	0.01	2.48	2.39	2.70
3 (6)	0.85	0.72	1.3	2.84	2.25	2.01
4 (5)	1.34	0.69	1.49	2.65	2.37	1.71

Table2. Restitution with different control configurations

Table 2 shows that check point error is consistent, even if more controls are added to support the model. The variations in errors are only due to migration of points to GCP from ICP domain. This reflects the excellent internal consistency of the product that enables the location accuracy enhancement through bias-compensation.

Discussion on Restitution

The results imply that only bias terms in RPC terms are being redefined, i.e. the 'shift' component (locational shift) is improvised during triangulation, while the drift, if any, is removed through tie points. The approach followed here is commonly known as *User-side RPC refinement.* It is technically feasible to introduce these corrections during product generation stage itself, which means raw RPCs possess better plan accuracy.

DEM EXTRACTION

Two evaluations have been carried out with CartoDEM; the first with the 1m cell DEM and then with research grade C-band SRTM DEM. The model contains broadly two type of landuse: urban and open flat lands. Appropriate strategies, as available in the DEM extraction software, are adopted. Correlation Coefficient of 0.8 is adapted for both types of landuse. 5m is the cell size of CartoDEM.

Low urban: With this strategy, regions are processed with a Search Size of 11x3 pixels and a *DTM Filtering* setting of *Moderate*. .

Flat area: With this strategy, regions are processed with a Search Size of 7x3 pixels and a *DTM Filtering* setting of *High*. In this strategy, a small search size is adequate because of the absence of high relief, which causes errors.

LandUse	Search Size In pixels	DEM Filtering	Correlation size In pixels
Flat areas	7 x 3	High	7 x 7
Low urban	11x 3	Moderate	7 x 7

Table 3. DEM Extraction Strategy

Demarcating the Bare Earth Area

Bare earth is delineated by filtering the high raised objects like buildings, trees, bushes and other manmade structures. To derive this, initially DEM is converted into point data and later non-ground points are filtered with the parameters adopted in viz., (1) iteration angle (determines the maximum slope between initial points and new points); (2) iteration distance (maximum distance of a new point from its closest ground point) and (3) maximum terrain angle (limit for the maximum terrain angle in the derived ground) by comparing with adjacent points in iterative manner. Terrascan software is used for this.

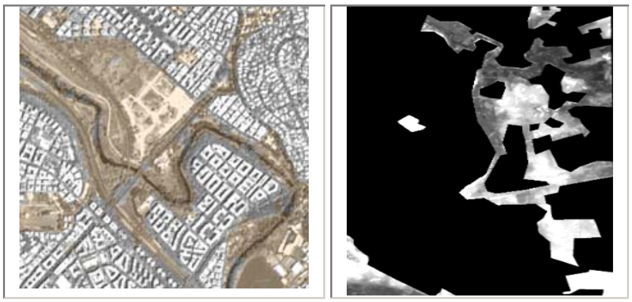

Figure 5.Open area demarcation (highlighted in brown) using slope criterion; and the total open area used for evaluating 1m-cell DEM

DEM Discussion

The DEM obtained through automatic matching is largely error-free; i.e., sinks and spikes are insignificant. The near-simultaneous imaging of stereo-constituents has facilitated this.

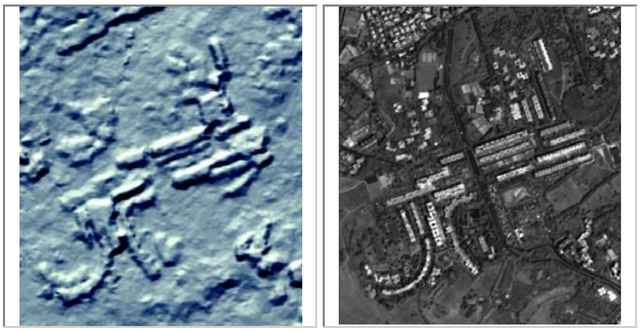

Figure 6. 5m-cell CartoDEM and corresponding AFT orthoimage

Reference DEM	1m cell DEM	SRTM DEM
Number of Points	17810677	812
Max. Abs. Error	7.5m	21.67m
Mean Abs. Error	3.57m	6.12m
Absolute LE90	6.36m	11.38m
NIMA Abs. LE90	3.39m	6.69m

Table 4. DEM Accuracy Assessment

ORTHOIMAGE EVALUATION

As is conventional, the AFT image is preferred for orthorectification, due to its near-nadir imaging.
Every 1m DEM error will result in a plan error of 4.3 cm, if AFT image is orthorectified. (The corresponding displacement is 48cm for FORE orthoimage).

The RMSe observed from 16 check points (points 5,6,9,19,21,23,24,29,31,3439,40,41,44, and 45) is 3.83m. The maximum positional error occurring at point 21 is 6.26m.

The RMSe observed from the same 16 check points of Orthoimage generated using SRTM DEM is 4.39m. The maximum positional error occurring at point 21 is 9.85m.

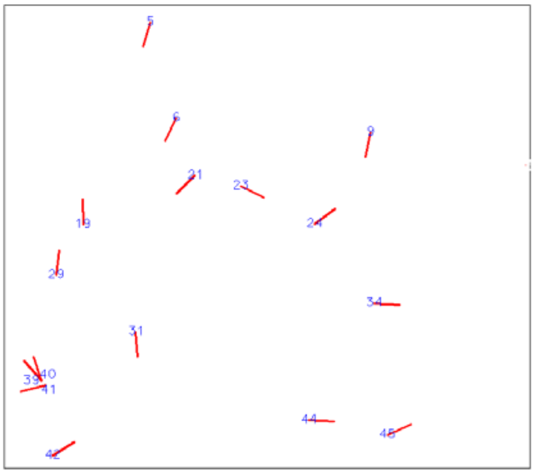

Figure 7. Error vectors of check points measured on Orthoimage (magnified 400 times).

Modeling AFT Image When External DEM is Used for Orthorectification

The monoscopic image of AFT camera is modeled by refining its RPCs. When one GCP is used, the check point RMSe (in plan) is 4m. With two or more points, the RMSe is marginally increased to 3m. This approach will be helpful when the user is equipped with legacy DEM.

MAPPING FROM THE ORTHOIMAGE

Table below shows the features that could be extracted from the AFT orthoimage for the study separately done for a different urban area [Narendar and Murali Mohan 2005]. Various features like Roads, Railway line etc. are extracted from the orthoimage in GIS compatible format.

Features	Feature Class
Cultural features (polygon)	Buildings, Group of Buildings, Parks, Play Grounds, Swimming Pools, Stadia.
Transportation (line)	Metalled roads, Unmetalled roads, Bridges, Culverts, Flyovers, Lane, Footpaths, Railway Lines, and Traffic Island (polygon)
Vegetation	Single (point), Grove (polygon), and Plantation (polygon).
Hydrography (polygon features)	Water_filled river, Dry river, Water filled and Dry Streams, Drains.
Hydrography (point features)	Embankments, Overhead tanks, Ground level reservoirs.
General (polygon)	Marshy lands, Rocky areas, Scrub lands, and Quarry sites.

Table 5. Culturable features mappable from Cartosat-I

Maintaining orthogonality while capturing the building edges is somewhat tedious. Interpretation of scrublands adjacent to agricultural land is difficult. As the data is panchromatic, color sharpening may improve the interpretation. Dense residential areas are generalized and captured as 'group of buildings'. By-lanes in the densely populated urban areas could not be captured confidently.

To capture an area feature 4 pixels x 4 pixels is required. i.e. feature which is occupying more that 8 m dimensions can be captured. Hence, the minimum mappable unit from Cartosat-I data is 64 sq.m.

CONCLUSIONS

1. One GCP is adequate for stereo restitution of Cartosat-I model.

2. DEM accuracy of CartoDEM, measured as NIMA absolute LE90, is 3.39m and 6.69m when compared with 1m-DEM and SRTM 3-arc second DEM respectively.

3. If the user has a legacy DEM, then only AFT image can be modeled requiring 2 GCPs for orthorectification.

4. The geometric accuracy and information potential of Orthoimages and DEM provided by the Cartosat-I Mission can be exploited for (a) updating 1:25,000 and 1:50,000scale maps, (b) making fresh topographic maps at 1:25,000 (c) making thematic maps at 1:10,000 scale and (d) Contouring at 10m interval.

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