The Indian Journal of Spatial Science Vol - 5.0 No. 1 Summer Issue 2014 pp. 56 - 61

The Indian Journal of Spatial Science

EISSN: 2249 - 4316 homepage: www.indiansss.org ISSN: 2249 - 3921

Generation of DSMs and Orthoimages from CARTOSAT – 1 Stereo Imagery — a case study of Bhopal, India

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Article Info

Article History
Received on:
12 October 2013
Accepted in *Revised Form* on:
31 December 2013
Available *Online* on and from:
20 March 2014

Key Words
Digital Surface Model
Cartosat-1
Stereo Image
Orthorectification

Abstract

The new and very high space resolution satellite images as CARTOSAT-1 open new possibilities for mapping purposes and extraction of digital surface models (DSMs) and orthorectified images. These DSMs are generated by stereomatching from very high resolution (VHR) satellite stereo-pairs imagery. The main aim of this work is the comparison between two commercial digital photogrammetric solutions for generating DSMs and orthophoto from a Cartosat-1 stereo-pair. The first photogrammetric software package used in this work is OrthoEngine from PCI Geomatica v. 10, developed by PCI Geomatics (PCI Geomatics, Richmond Hill, Ontario, Canada). OrthoEngine implements both the physical model developed by the Canada Centre of Remote Sensing (CCRS) and the rational function (RF) model where rational polynomial coefficients are supplied by the vendor and later refined by means of the first order linear functions (RPC1).The second commercial software package is the Leica Photogrammetric Suite (LPS) by ERDAS Inc.

Introduction

On 5 May 2005, the Indian Space Research Organization (ISRO) launched Cartosat-1, the eleventh satellite of its IRS constellation, dedicated to the stereo viewing of the Earth's surface. Cartosat-1carries two high-resolution imaging cameras: the afterward looking camera (Aft) and the foreword looking camera (Fore), both able to collect panchromatic images with a spatial resolution of 2.5 m on the ground. The imaging cameras are fixed to the spacecraft to acquire near-simultaneous imaging of the same scene (with a delay of 52 s between the Fore and the Aft acquisitions) from two different angles: + 26° with respect to nadir for the Fore camera and - 5° with respect to nadir for the Aft camera. Several researchers (Dabrowski et al, 2008; Gianinetto, 2009) have generated DSMs from Cartosat-1 data. The terms Digital Elevation Model (DEM), digital terrain model (DTM), and DSM is often used as synonyms (Martha et al., 2010). A DSM represents elevation of every natural and / or artificial object like building, vegetation etc. as seen by sensor above the earth. When a terrain data portrays only the elevation information of bare earth, it is termed as either DEM or DTM. The main aim of this study is to compare the two commercial digital photogrammetric solutions for generating DSMs and orthophotos from a Cartosat-1 stereo pair. The root mean square error (RMSE) at the ground control points (GCP) is the most popular method for accuracy assessment.

Study Area

Bhopal city of Madhya Pradesh, India (Fig.1A) is located between 23°09´N and 23°21´N latitude and 77°19´E and 77°31´E longitude. The urban development of Bhopal can be traced back as early as 11th century. Till 2013 the Bhopal municipality area is divided into seventy wards (fig.1B). Since the total municipality boundary covers large area (285 km^2), a smaller test area (1.42 km^2) is selected (Fig.1C). The test site (Ward No. 30) is composed of buildings of various heights.

Data Used

A. Satellite Imagery

The data set used in this research has been acquired on

16th Feb 2012. It is one set of stereo pair, provided as OrthokitGeoTiff format, referenced to the WGS84 ellipsoid and datum. Other specific information about the data is given in Table -1.

B. Ground Control Points

Six Ground Control Points (GCPs) are collected using a high performance DGPS with about 50 cm horizontal accuracy and 8 m vertical accuracy. The GCPs are acquired with UTM projection and WGS 84 datum. The points are all located on the ground. Those GPS points are well distributed throughout the test area (Fig. 2).

Methodology

Generating DSM from Cartosat-1 Stereo Pair

Efforts, based on digital matching and additional image processing techniques, have been made in digital photogrammetry to develop automatic methods for surface reconstruction. Software packages have been developed by several companies to reconstruct the surface and automatically generate DSMs using optical stereo satellite data. OrthoEngine 2012 by Rolta Geomatica Inc. and Leica Photogrammetric Suite (LPS) by ERDAS Inc. are such two commercial softwares which are used in this research. Two 5 m DSMs are generated separately from Cartosat data using above softwares.

The processes of automatic DSM extraction using LPS and OrthoEngine are described in Table - 2. It shows that both LPS and Orthoengine do automated image matching before DSM extraction. The process of image matching in LPS and Orthoengine is described in following sections.

Image Matching in LPS and Orthoengine

Theoretically, the main tasks in image matching are : i) selecting a matching point in one image, finding its conjugate point in the other (stereomate) image, ii) computing 3D position of the matched point in object space and finally, iii)assessing the quality of the matching.

i) Selecting Matching Points

During Image Matching in LPS, a correlation window exists on the reference image and a search window exists on the neighbouring overlapping image. The cross-correlation coefficients are calculated for each correlation window among the search window. The correlation coefficient is considered as the measure of similarity between the image points appearing within the overlapping areas of image pair. The correlation coefficient is set to 0.8 (default) and the search window size is set to 27 X 27 pixel (default is 21x 21 pixel window). Higher value for search window increases the number of matched points. Total 110 tie points are generated in the overlapping area whose ground coordinates are not known (Fig.3).

On the other hand, OrthoEngine extract matching points on the two overlapping images from a search for pixels of corresponding contrast and brightness. This procedure is based on a mean normalized cross- correlation matching method with a multi-scale strategy to match the image using the statistics collected in the defined windows. Using “automatically collect tie points” window, total 64 matched points are generated in the overlapping area (Fig.3).

ii) Computing 3D Position of the Matched Points

To calibrate the z values of the matched (tie) points software needs geometric model or math model (Table 2). In both softwares, rational function or RF model is defined as geometric model. The Rational Functions Math Model uses a ratio of two polynomial functions to compute the image row, and a similar ratio to compute the image column. All four polynomials are functions of three ground coordinates: latitude, longitude, and height or elevation. The polynomials are described by using a set of up to 20 coefficients, although some of the coefficients are often zero (Orthoengine Userguide, 2012). Such coefficients are derived from orbit and attitude information. The polynomial coefficients, often called Rapid Positioning Capability (RPC) data are provided by vendor with Cartosat-1 data.

Sometimes the accuracy of the sensor-oriented RFM is not sufficient. Additional information like Ground Control Points (GCPs) is required to ensure a fairly desirable level of geo-positioning accuracy (Wang et al. 2011).To refine the math model we used first order polynomial for which minimum number of GCPs required is 4 per image (Orthoengine Userguide, 2012). We collected six well distributed GCPs (fig.2). In LPS, Using classical point measurement tool six ground points are added to the images. In Orthoengine, Same six ground control points are added to the images using “collecting Ground Control Points Manually” tool. Figure 3 showing distribution of GCPs along with tie points in the stereo pairs.

iii) Assessing the Quality of Match

To assess the quality of Image Matching Root Mean Square Error (RMSE) is calculated. Table 3 shows the RMSEx, RMSEy values for the residuals computed at 6 GCPs along X and Y axes after the image matching performed of the Cartosat-1 stereopair. Residual errors are the difference between the coordinates entered for the ground control points (GCPs) where those points are according to the computed mathmodel. Residual errors reflect the overall quality of the math model. In general, residual error up to one pixel reflects the high accuracy of the model. Table 3 shows RMSE values are lower in LPS compared to Orthoengine. It means the math model worked better in LPS compared to the Orthoengine. Once the image matching is done the next step is automated extraction of DSM. The following sections analyze DSM in both softwares.

Automated Extraction of DSM

The Automated Terrain Extraction (ATE) module of LPS allows for the creation of various DTM output types. This includes raster DEM, Terramodel TIN, ESRI 3D Shape file, and ASCII file. In DTM extraction window, raster DEM is chosen as output type and 5m is set for output cell size considering the Ground Sampling Distance (GSD) of the original stereo pair is 2.5 m. A recent study described the best resolution as twice the satellite's image pixel size to avoid degradation of the DSM's structure (Gianinetto, 2009).In order to create a raster DEM output, the matched points are used as reference points to interpolate an elevation value to create a raster grid DEM. The option for adaptive ATE is also chosen with default zero pyramid level. Adaptive ATE is an advance algorithm which uses a global DEM to initialize a surface model and iteratively refines it with image registration on different pyramid levels. The output raster DEM is the DSM (Fig.4A) as it consists of elevation of objects over the earth surface.

In Orthoengine, the process of automated DEM extraction is divided into two steps (Table - 2). For every DEM, the epipolar images (were) are generated with 2.5 m GSD (down sample factor of 1).Epipolar images are stereo pairs that are reprojected so that the left and right images have a common orientation, and matching features between the images appear along a common x axis. Using epipolar images increases the speed of the correlation process and reduces the possibility of incorrect matches. The number in “Down Sample Factor” determines the number of image pixels and lines that will be used to calculate one epipolar image pixel. To create DSM, “Automatic DEM extraction” window is opened in Orthoengine and epipolar pairs are selected. The level of detail is set “high” which assures that the process continues until correlation is performed on images at full resolution. “Pixel sampling interval” is selected 2 to produce 5m output DEM. Advance algorithm like “Wallis filter” is selected to improve the accuracy of the elevation calculation in dark area, such as buildings and terrain shadow or dark vegetation. The option for “Encoded DEM” is chosen to get georeferenced DEM. The output raster DEM is the DSM (Fig.4B) as it consists of elevation of objects over the earth surface.

Results and Discussion

Comparing the Accuracy of the DSMs

The accuracy of DSMs generated in two different softwares is assessed both quantitative and qualitatively. Qualitative assessment involves visual comparison. Figure 4 compares two DSMs of the same test area generated in two different softwares. Visually, Orthoengine generated DSM (4B) contains more detail compared to LPS generated DSM(4A). The edges of urban features specifically buildings are sharper in fig. 4B compared to fig.4A. The reason might be the object filtering used by adaptive ATE in LPS (refer section 4.1.2). Object filtering is a blunder elimination technique within adaptive ATE which removes most spikes in elevation resulting in the smoothing of building edges.

On the other hand, filter used in Orthoengine improves the accuracy of the elevation calculation and does not produce smoothing effect.

From visual comparison it is evident that DSM generated by Orthoengine is preferable over LPS generated DSM if the objective is urban change detection or city modeling which requires detection of individual buildings.

For quantitative comparison, calculated elevation values are extracted from two DSMs for six GCP points and compared with DGPS elevation values. While ATE module within LPS automatically generates an accuracy report for DSM, Orthoengine does not have that option. Using raster DSM layer and vector GCP layer RMS report is generated using advanced algorithm like “ELVECRMS” in Geomatica Focus. Content of the reports obtained from both LPS and Ortho engine are shown in Table 4 and 5.

Table 4 shows that residual error ranges from -3.6556 to 15.6263 m for elevation value in LPS. On the other hand, residual error ranges between -3.56 and 17.82 m in Orthoengine. It implies the fact that range of difference between calculated value and DGPS values is higher in Orthoengine compare to LPS. From given residual values, mean error and mean absolute errors are calculated and compared in the following table (table 5). RMSE values for six GCP points are also calculated and compared as part of accuracy assessment. Small difference between calculated value and DGPS value resulted lower Mean Absolute Error value in LPS compare to Orthoengine (table 5). Not only the difference is small but the variation of difference is also low. Lower RMSE value for LPS confirms the fact.

Comparing the Orthorectification

Once the DSMs are processed in both softwares they are used in respective software to generate orthorectified images. Orthorectification converts imagery into map-accurate form by removing camera and terrain related distortions from the imagery through the use of sensor and terrain (elevation) information. The quality of the orthorectified image is directly related to the quality of the rigorous math model and the DEM (Orthoengine Userguide, 2012). Same math model which is used for DSM generation (refer section 4.1.1.ii) is also used for orthorectification. Aft image of stereopair is selected for orthorectification and DSMs are defined as elevation source. Band A is selected because of its near nadir acquisition angle. The resolution of output orthoimage is set to 5m to match with the resolution of elevation dataset. Figure 5 compares the orthoimages generated from Band A.The visual comparison shows both orthoimages contain same level of detail. To check whether they are matched precisely a building boundary is digitized on top of image A and overlaid on image B. It seems image B is slightly displaced towards north compare to image A (Fig.6).

Conclusion

The main aim of this research is to compare two commercial digital photogrammetric solutions for generating DSMs and Orthoimages from a Cartosat-1 stereo-pair. Cartosat-1 stereo model (Path 0532 Row 290) containing Bhopal city is chosen for analysis. Since a Cartosat-1 scene covers a large area, a smaller test area is selected. The softwares used are Orthoengine (v.10) by PCI Geomatica and LPS (v.11) by Erdas Inc. Digital Surface Model (DSM), can be generated through the use of automatic image matching.

The technique of image matching use rigorous math model to calibrate Z values for matched points. Those matched points are used as reference points to interpolate an elevation value to create a raster grid DSM. The math model used is rational function which is supplied by vendor for Cartosat-1 data. To refine the math model six GCP points well distributed over test area are collected and used in image matching process. The results of image matching performed in two different softwares are compared and it is found that that math model is more accurate in LPS compare to Orthoengine. Accuracy of math model is important because precision of DSM depends on it.

The DSM generated in two different softwares is compared both visually and statistically. Visual comparison reveals the superiority of Orthoengine generated DSM over LPS generated DSM. On the other hand, statistically, LPS DSM is more accurate than Orthoengine DSM. Once DSMs are processed they can be used for orthorectifying the stereo models. Two orthoimages are produced in two different softwares using Aft image of Cartosat 1 stereo pair. Visually there is no distinct difference between orthoimages generated in two different softwares. The above analysis and discussion shows that while Orthoengine produce visually pleasing DSM, DSM generated through Orthoengine is statistically more accurate. Therefore, the choice of the software depends upon the objective of the researcher.

Acknowledgement

I am sincerely thankful to Professor Katiyar and his students of Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh for helping me to conduct the DGPS Survey.

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Table – 1: General Characteristics of the Cartosat-1 Image (used in this study)

Sensor	Path	Row	Orbit No	Sun Elevation	Sun Azimuth
PAN_AFT / PAN_FORE	0532	290	36719	47.94	144.461

Table – 2: Hierarchical Steps of Generating DSM in LPS and OrthoEngine

Steps	LPS	OrthoEngine
1	Creating of Block files or *.blk files: Data Input and Geometric Model to be set	Generating Project or *.prj file: Geometric Model and Output Projection to be defined
2	Setting up Internal Geometry: Images are Projected to Epipolar Geometry	Data Input: both Aft and Fore Images of Stereo Pairs are added.
3	Generation of Mass Point by Automatic Image Matching	GCP Collection and Image Matching
4	GCP Collection and RPC Correction	DEM from Stereo: a) Create Epipolar Image b) Extract DEM automatically
5	DTM Extraction (type set to Raster DEM)	

Table – 3: Accuracy at the 6 GCPs for Match Model used in Image Matching Technique

Software	$RMSE_X$ (m)	$RMSE_Y$ (m)	$RMSE_{Total\ Image}$ (Pixel)
OrthoEngine	6.34	7.20	4.02
LPS	3.630	2.314	0.697

Source: Computed by author

Table – 4: Comparing Vertical Accuracy between Block GCP and DSM (Part-1)

Point Id	DGPS Value (m)	Calculated Value$_{(LPS)}$ (m)	Residual$_{(LPS)}$ (m)	Calculated Value$_{(OrthoEngine)}$ (m)	Residual$_{(OrthoEngine)}$ (m)
A	465.599	469.4079	3.8089	462.90	-2.70
B	467.453	470.3809	2.9279	463.89	-3.56
C	473.494	475.9545	2.4605	471.85	-1.65
D	458.406	454.7504	-3.6556	456.24	-2.17
E	469.96	485.5863	15.6263	487.78	17.82
F	459.995	463.5344	3.5394	469.37	9.38

Source: Computed by author

Table – 5: Comparing Vertical Accuracy between Block GCP and DSM (Part-2)

	LPS	Orthoengine
Mean Absolute Error	5.3364	6.212681
Mean Error	4.1179	2.851453
RMSE	7.0617	8.492889

Source: Computed by author

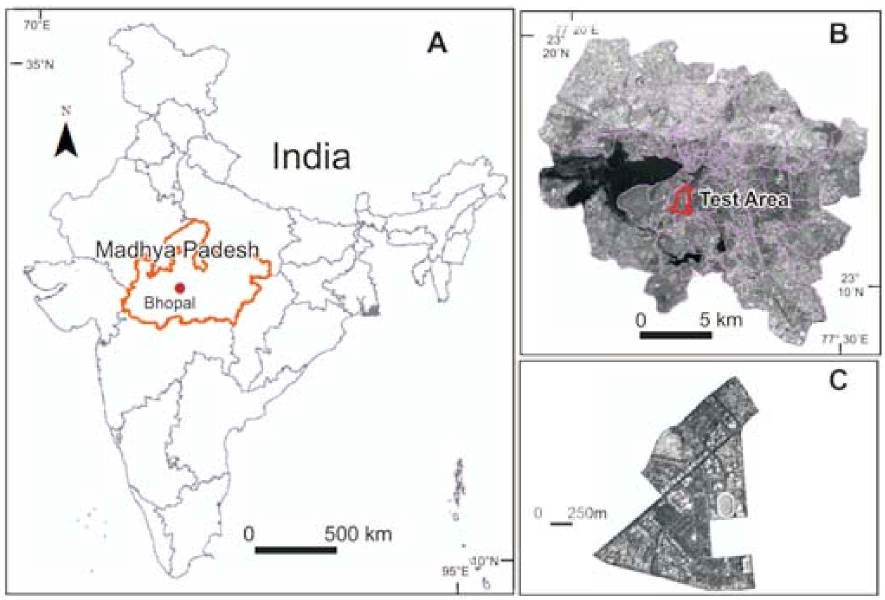

Fig. 1: Location Map a) Bhopal in India, b) Wards of Bhopal Municipal Area, c) Test Area (Ward No. 30)

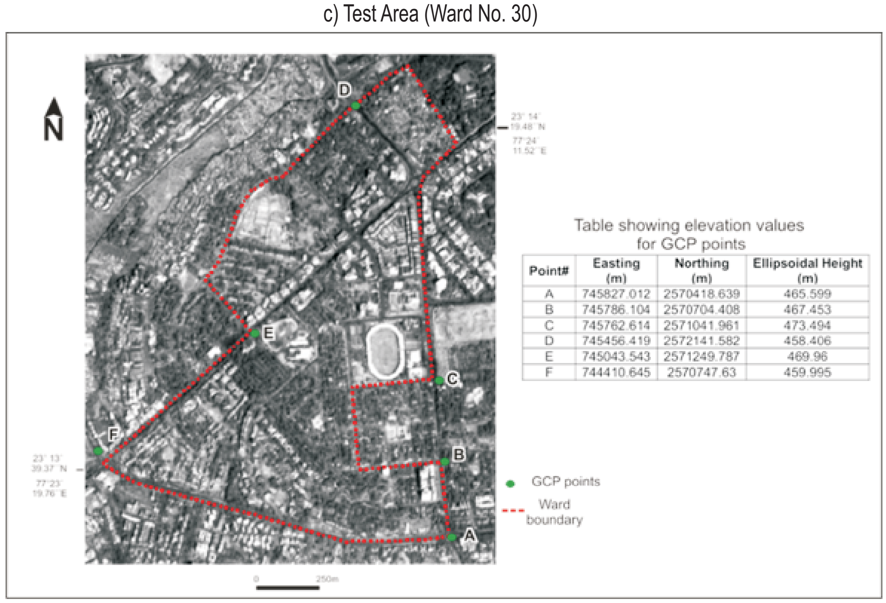

Fig. 2: Location of GCP in Map and corresponding X,Y,Z Values in Table

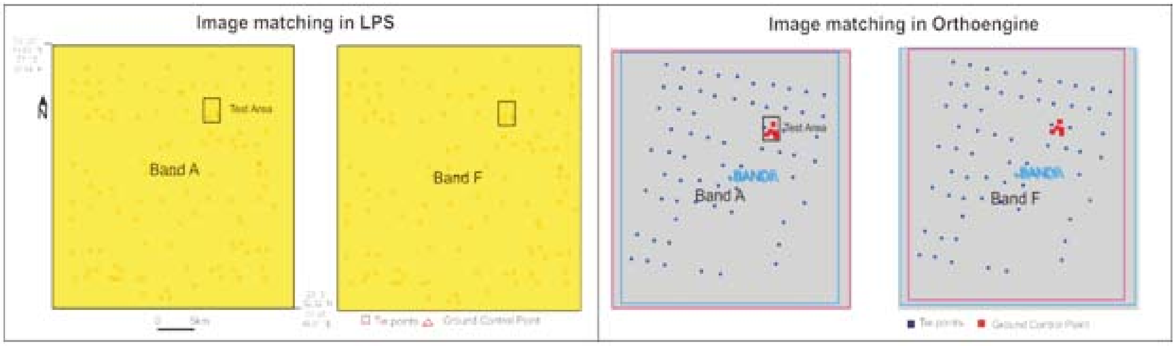

Fig. 3:Comparison between Distribution of Tie and GCPs on Stereo Pair in both Software

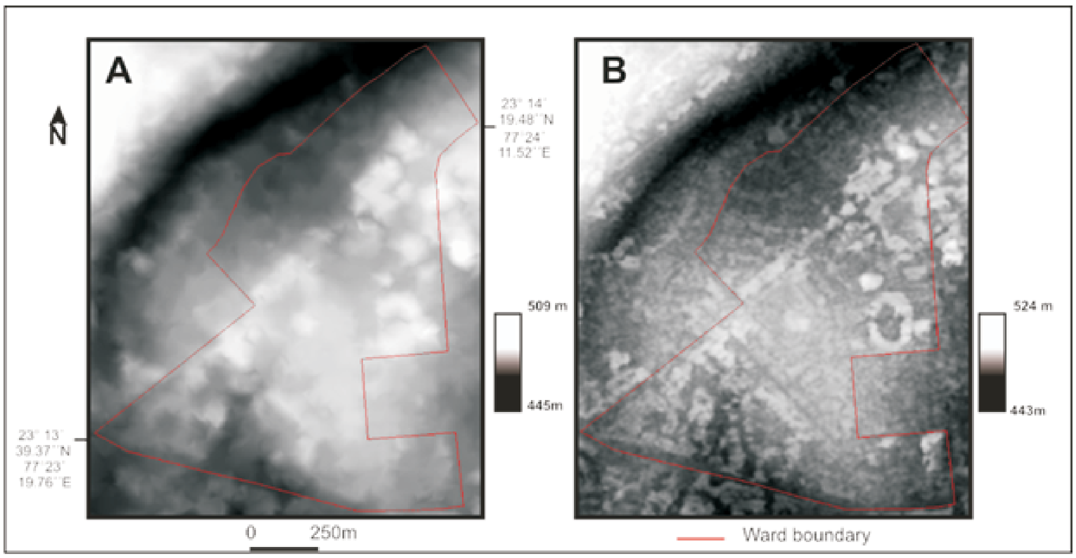

Fig. 4: Comparing DSMs extracted through (a) LPS and (b) OrthoEngine

Fig. 5: Comparing Orthoimages generated in a) LPS and b) OrthoEngine

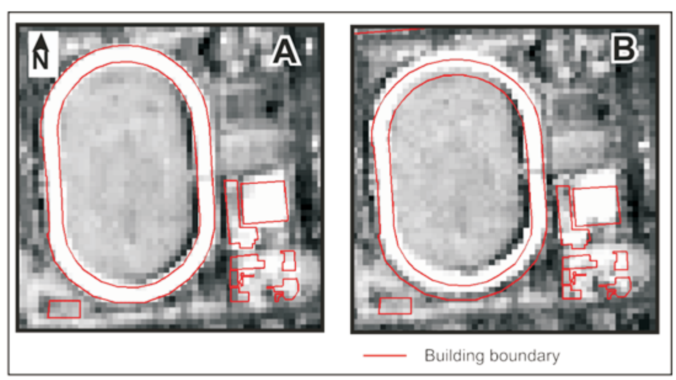

Fig. 6: Orthoimage B is different from Orthoimage A in Orientation and Shape

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