UTILIZATION POTENTIAL OF HIGH RESOLUTION STEREO DATA FOR EXTRACTING DEM AND TERRAIN PARAMETERS

P. Jayaprasad, Ritesh Agrawal, S. K. Pathan*

Space Applications Centre, Indian Space Research Organisation (ISRO), Ahmedabad-380 015, India - (jayaprasadp, ritesh_agrawal, subhan_kp)@sac.isro.gov.in

***Secretary Commission IV**

KEY WORDS: CARTOSAT-1, Stereo data, RPCs, DGPS, DEM, Ortho Image, Accuracy Assessment, terrain parameter

ABSTRACT:

Cartosat-1 data provides along track stereo data continuously with its fore and aft cameras. 10 bit quantization and near real time imaging between the stereo pairs which improve the image matching accuracies. Stereo data along with Rational Polynomial Coefficients (RPCs), provides an opportunity for photogrammetric processing for DEM and ortho image generation. The present study focuses on the effect of the number of Ground Control Points (GCPs) and polynomial order for the refinement of RPCs for generating an accurate Digital Elevation Model (DEM). 10 GCPs were used in the refinement process and 9 Independent Check Points (ICPs) used for accuracy analysis. Both GCPs and ICPs were derived using Differential GPS survey (DGPS). Effect of DEM resolution while generating the Ortho Image is also studied. Terrain parameters such as slope, aspect and drainage network have been automatically extracted. The drainage network was extracted at different DEM resolution using similar area specific (5000 m^2) accumulation threshold and a comparative analysis of the order of the drainages has been carried out. The accuracy analysis shows that RMS errors of DEM and ortho images were within 5m both in elevation and planimetry respectively with 10 GCPs and polynomial order 2.

1. INTRODUCTION

Launch of CARTOSAT-I on 5th May 2005 has opened a new era in civilian community for addressing newer applications at larger scale. With its capability to acquire stereo images with Fore (+26º) and Aft (–5º) cameras and a nominal B/H ratio of 0.62, it gives a stereo data at 2.5 m spatial resolution. Less than a minute interval acquisition time between the stereo pair makes an ideal imaging condition. The repetitivity of the satellite is 126 days with a revisit capability of 10 days and the scene size of 30 km * 30 km has shown tremendous potential in the field of satellite photogrammetry. Stereo pairs are formed either from across track geometry or from along track geometry. Advantageous and disadvantages of the along track and across track stereo viewing mainly depends on the slope and aspect of the terrain towards the viewing geometry and illumination conditions of the two imageries. The Fore and Aft cameras onboard provides a continuous strip of stereo data. The mono-scopic camera on board IRS 1C/1D, Ikonos, SPOT and QuickBird generates a stereo pair by steering the camera (along/across track depending on the capabilities) and provides a limited stereo coverage rather than a continuous one. For three cameras system, in addition to fore and aft imagery, nadir imagery also provides the satellite capable of taking triplet imagery (ALOS-PRISM).

Satellite Photogrammetry techniques have been extensively used by the scientific community in deriving high resolution DEM, Ortho image and terrain parameters such as slope, aspect, contours, drainage etc. Digital Elevation Model (DEM) has become an inevitable component in most of the remote sensing applications viz. infrastructure development, watershed management and development, hydro-geomorphology, urban morphology, disaster management etc. Keeping these applications in view, the current study aimed at exploitation of Cartosat-1 stereo data for various applications.

Rational functions models (RFMs) have gained popularity, with the recent advent of high resolution data supplying Rational Polynomial Coefficients (RPCs) along with stereo / mono data. Providing these coefficients along with stereo data, instead of delivering the interior and exterior orientation parameters and other properties related to physical Sensor, one can proceed to satellite photogrammetric processes which approximate the sensor model itself.

A detailed study of the RFMs for photogrammetric processing has been carried out by Tao and Hu (2001). Di et. al. (2003) demonstrated different ways to improve the geo-positioning accuracy of Ikonos stereo imagery by either refining the vendor provided RF (Rational Function) coefficients, or refining the RF derived ground coordinates. Poon et al. (2007) focuses on Digital Surface Model (DSM) generation from high resolution satellite imagery (HRSI) using different commercial of the shelf (COTS) packages. They validated the stereo DEM with InSAR DEM for different land forms. Nadeem et. al (2007) validated DEM generated from Cartosat-1 stereo data. Crespi et. al. (2006) evaluated the DSM by comparing the heights of several buildings and points on the road axis derived from a large scale (1:2000) 3D map. Fracer and Hanley (2005) demonstrated the wide applicability of bias compensated RPCs for high accuracy geo-positioning from stereo HRSI for a mountainous terrain. Chen et. al. (2006) compared geometrical performance between rigorous sensor model (RSM) and RFM in the sensor modeling of FORMOSAT-2 satellite image. Dabrowski et. al. (2006) evaluated DEMs generated with different numbers of GCPs from Cartosat-1 stereo data at large number of evenly distributed check points. Similar attempts to evaluate the accuracy of the DEM using different number of GCPs have been made by Michalis and Dowman (2006) and Rao (2006). RFM based processing methods and mapping applications was developed for 3D feature extraction, ortho rectification and

RPC model refinement (Tao et. al. 2004). Ritesh et. al (2006) evaluated various algorithms for generation of drainage network from Cartosat-1 DEM. Li et. al. (2007) studied the 3D geo-positioning accuracies by integrating IKONOS and QuickBird stereo images using rational polynomial coefficients.

On the basis of these demonstrative studies, an attempt has been made to find out the planimetric and elevation accuracies of the DEM and Ortho image from Cartosat-1 stereo data. The RMS error was computed at GCPs and Check points by varying the number of GCPs and polynomial order for refinement of RPCs. Terrain parameters such as slope, aspect, and drainage network has been extracted from DEM.

2. OBJECTIVES

The prime objective of the study is to generate DEM using Cartosat-1 data and derive terrain parameters. The detailed objectives of the study are as follows.

- Experimental design and execution of DGPS survey and establishment of Ground Control Points (GCPs).
- To study the effect of number of GCPs and order of polynomial for RPC refinement for the generation of DEM
- Generation of DEM and Ortho image from Cartosat-1 stereo data
- Effect of DEM resolution / accuracy on ortho image generation
- To retrieve the terrain parameters such as slope, aspect and drainage network. Comparative evaluation of the drainage order derived from different DEM resolutions.

3. STUDY AREA

Part of Alwar District, Rajasthan state, India was taken up for the study. The area falls between 27°30’ and 27° 50’ in latitude and 76°30’ and 76°50’ in longitude respectively. The study area has heterogeneous terrain with elevation ranging from 200 to 600 meters in WGS 84 datum approximately. The major cultural features include Arravali range, Alwar city, Shyamaka Reserve Forest etc.

4. DATA USED

Cartosat-1 stereo data acquired on 4th November, 2005 was used for the study. The details of the data are given in Table 1.

Sensor	Path	Row	Orbit No	Sun Elevation	Sun Azimuth
PAN_AFT/ PAN_FORE	0523	0270	2713	44.5740º	159.6077º

Table 1. Details of the Cartosat-1 data used

DGPS observations at Control points, IGS data observations, ancillary files and GPS satellite precise orbit file.

5. RATIONAL FUNCTIONS

A sensor model relates 3D object point positions to their corresponding image positions through the collinearity condition equations. The RFM relates object space coordinates to the image space coordinates. The image pixel coordinates (x, y) are expressed as ratios of polynomials of ground coordinates (X, Y, Z). Generally they are represented as third order polynomials. Ratios have a forward form:

$$x = P_1 (X,Y,Z) \; / \; P_2(X,Y,Z) \qquad (1)$$

$$y = P_3 (X,Y,Z) \; / \; P_4 (X,Y,Z)$$

This equation is called upward RF. Usually RF model is generated based on a rigorous sensor model.

P_i (i =1,2,3 and 4) are the polynomial functions with the following general form:

$$P_i = a_{1i} + a_{2i} X + a_{3i} Y + a_{4i} Z + a_{5i} XY + a_{6i} XZ + a_{7i} YZ + a_{8i} X^2 + a_{9i} Y^2 + a_{10i} Z^2 + a_{11i} XYZ + a_{12i} X Y^2 + a_{13i} XZ^2 + a_{14i} YX^2 + a_{15i} YZ^2 + a_{16i} Z X^2 + a_{17i} Z Y^2 + a_{18i} X^3 + a_{19i} Y^3 + a_{20i} Z^3 \qquad (2)$$

The order of the terms is trivial and may vary in different literature. The number of coefficients in the polynomial can be reduced gradually by applying different conditions (P_2=P_4) & (P_2=P_4=1). The first coefficient in the denominator is known (a_2=a_4=1). A minimum of 7, 19, and 39 GCPs are required to resolve the first, second and third-order RFM having 14, 38 and 78 number of RPCs respectively.

Refinement with polynomials corrects the remaining error and refines the mathematical solution. Values between 0 and 3 can be selected to correct the original rational function model. The 0th order results in a simple shift to both image x and y coordinates. The 1st order is an affine transformation. The 2nd order results in a second order transformation; the 3rd order a third order transformation. In general, a 0th or 1st polynomial order is sufficient to reduce error not addressed by the rational function model. A higher order polynomial requires more GCPs.

6. METHODOLOGY

A standard methodology has been adopted for the generation of DEM, ortho Image and terrain parameter retrieval and is shown in Figure 1. It comprises of reconnaissance survey and DGPS survey, establishment of reference station by network adjustment with IGS stations, establishment of a sub reference station with respect to reference station, establishment of GCPs with respect to sub-reference station, stereo data analysis using RPCs and updation of RPCs using GCPs, generation of DEM, Ortho image, retrieval terrain parameter from DEM, accuracy assessment of DEM and ortho image, generation of DEM by refining Rational Polynomial Coefficients (RPCs) with different number and distribution of GCPs, validating the DEM, generating the DEM, Ortho images at the best check point RMSE and extraction of terrain parameters.

7. DATA ANALYSIS

Establishment of GCPs

One of the most important parameter for DEM generation and validation is to establish the coordinates of the GCP’s. The GCP coordinates are required for geo-referencing the satellite imagery and also in the bundle adjustment for generation of DEM. In addition to this, it is also required to have some GCP’s for validation of DEM. These were established using

GPS observations and post processing of the data in differential mode.

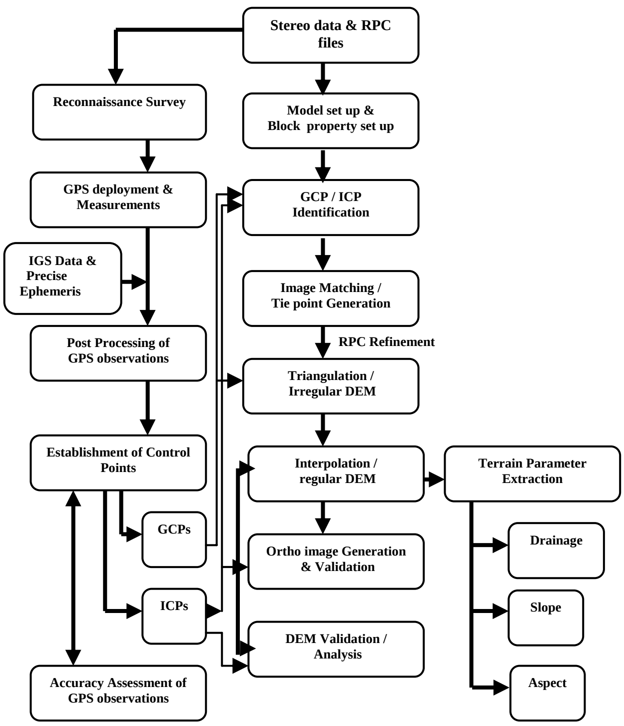

Figure1. Methodology flowchart for stereo data analysis, validation and extraction of terrain parameters

Post processing of GPS observations was carried out using Static Kinematic Interface (SKI Pro V 2.1) software. GPS data of six International GPS services for Geodynamics (IGS) stations, having a distance of 3000 km or less from the reference station, was downloaded in RINEX format along with precise ephemeris data. The reference station was established by network adjustment with IGS stations taking 3 days data. A sub-reference station was established in the study area with respect to reference station by taking observations for 24 hrs. The GCPs were established by base line processing with respect to sub-reference station. The common observation period was kept 1 hour between the sub-reference and GCPs. In all 19 GCPs were established. All the coordinates were in WGS-84 datum. The coordinates of GCP's derived from differential GPS measurements were validated using vector closure method at three non-collinear stations, reference station being one among them. The closing error of the triangle was computed by ($\sqrt{(\Sigma dx^2 + \Sigma dy^2 + \Sigma dz^2)} / \Sigma S$), where Σdx, Σdy, Σdz represent the sum of component vectors in x, y and z direction respectively (the misclosures in three directions) and ΣS represents the sum of the sides of the triangle. The closing error is better than 1 ppm.

Effect of Number of GCPs and Polynomial Order used in RPC Refinement, for Generating the DEM

GCPs are the inevitable components for generating an accurate DEM and Ortho images. Ortho rectification can be performed using RPCs provided along with data, with out any ground control information. These products will lack in the accuracy part. Leica Photogrammetric Suite v. 9.0 (LPS) was used for photogrammetric analysis in this study. Out of 19 GCPs, used in this study, 10 were used as planimetric and vertical control points, 7 were used as planimetric and vertical check points and 2 were used as vertical check points. More than 250 tie points were automatically generated. GCPs were used to refine the RPCs for the generation of DEM and the accuracy was assessed at check points.

Initially, no GCPs were used for refining the RPCs and planimetric and elevation accuracy at 9 check points was computed by triangulating. Number of distributed GCPs was varied by 1, 5, 8 and 10 and also the order of polynomial refinement. With each group of GCPs triangulation was performed for different polynomial order from 0 to 2 depending on the number of GCPs. For 0 and 1 GCPs the polynomial order 0 was taken. Accuracy at GCP and Check points were computed. The triangulation exercise was carried out by taking polynomial order 1 and changing number of GCPs as 5, 8, and 10. This was extended for polynomial order 2 for GCPs 8 and 10. The results are tabulated in Table 2.

No. of GCPs	Poly. Order	RMSE at Control Points (10 Full) (m)			RMSE at Check Points (7 Full + 2 Vertical) (m)		
		Lon.	Lat.	Ele.	Lon.	Lat.	Ele.
0	0				22.6	98.4	22.9
1	0				9.8	4.4	4.5
5	1	3.7	4.0	0.4	4.9	3.9	3.5
8	1	3.7	2.7	1.3	6.6	4.1	2.8
8	2	0.4	0.7	0.4	3.6	6.3	3.2
10	1	5.4	3.2	1.3	5.0	3.6	2.9
10	2	0.4	0.7	0.4	4.3	3.5	3.1

Table 2. Effect of Number of GCPs and Polynomial order for refinement of RPCs for DEM generation.

DEM and Ortho Image Generation

A combination of the order and number of GCPs having minimum RMS Error was selected for generating final DEM.

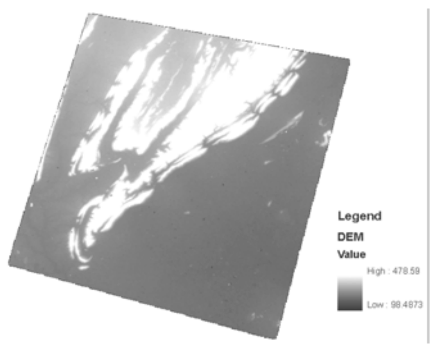

Figure 2. DEM for the study area

DEMs were generated at 2.5m, 5m and 10m pixel resolution for a subset. Subset was selected to reduce the number of irregular points for interpolation. Around 40 Lakh points were generated for the entire study area at 2.5 m resolution. Figure 2 & 3 shows the DEM and Ortho image generated for the study area.

Figure 3. Ortho-image for the study area

Effect of DEM Resolution / Accuracy on Ortho Image Generation

Ortho image was generated at 2.5 m by using DEM at different resolutions. The effect of resolution on ortho image generation is studied at different pixel resolution belonging to plain and undulating terrain. The positions at 10 points having distinct contrast are measured on three ortho images derived from different DEM resolution. Ortho image generated from 2.5 m DEM was taken as the reference and planimetric differences were computed at all the points. The results are tabulated in Table 3.

Difference in Location between Ortho images Generated (m)			
From 5m DEM & 2.5m DEM		From 10m DEM & 2.5m DEM	
Longitude	Latitude	Longitude	Latitude
0.0	0.1	1.0	-0.6
0.0	-0.1	0.9	-0.6
0.0	0.1	1.0	-0.5
-0.1	0.1	1.0	-0.5
0.0	0.0	1.1	-0.5
0.1	0.0	1.1	-0.5
0.1	0.0	1.1	-0.5
0.1	0.0	1.1	-0.5
0.0	-0.1	1.0	-0.6
0.0	0.0	1.0	-0.6

Table 3. Planimetric Difference in Ortho image generated using DEM at different locations

Retrieval of Terrain Parameters

DEM corresponding to a micro watershed and are shown in figure 4. Slope, aspect and drainage network has been extracted from DEM. Slope and aspect is an important parameter in the study and modeling of soil erosion, landslide, watershed management and hydrological applications.

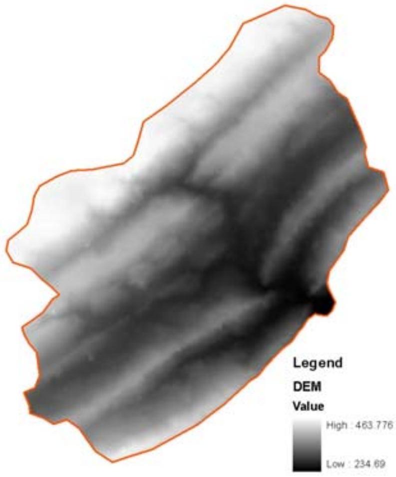

Figure 4. DEM of Microwatershed for terrain Parameter retrieval

The slope was calculated for each cell and was categorized into 9 standard categories. Similarly the aspect was also calculated for each cell and categorized into 8 categories. The slope map and their categories are shown in figures 5a and 5b respectively. Similarly aspect map and their categories are shown in figures 6a and 6b respectively.

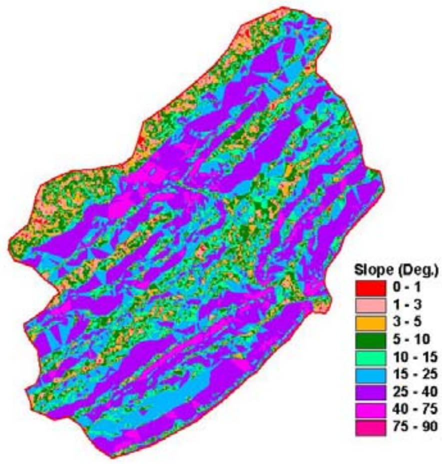

Figure 5a. Slope map

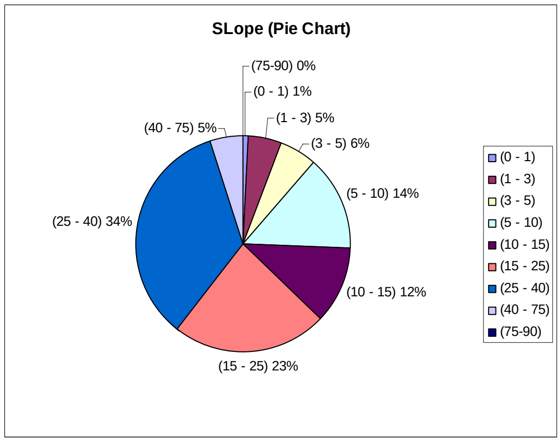

Figure 5b. Slope Categories

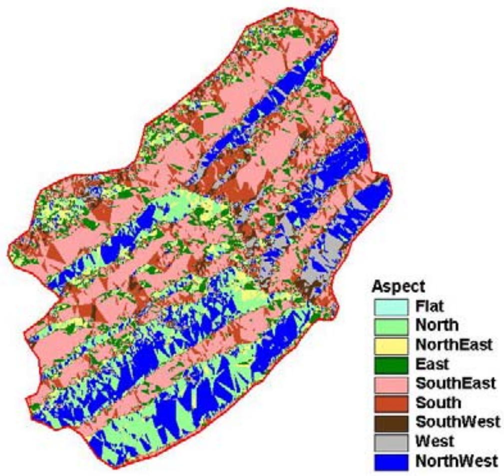

Figure 6a. Aspect map

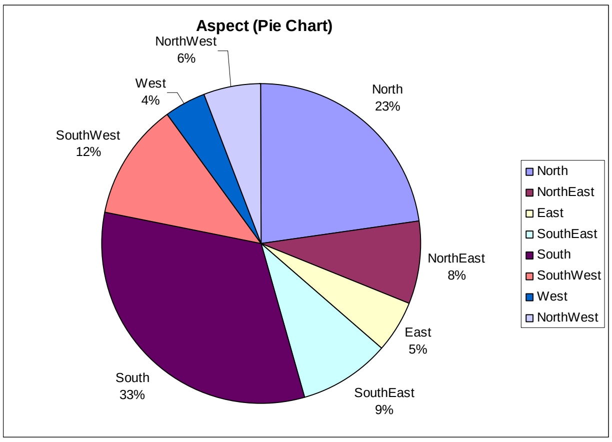

Figure 6b. Aspect Categories

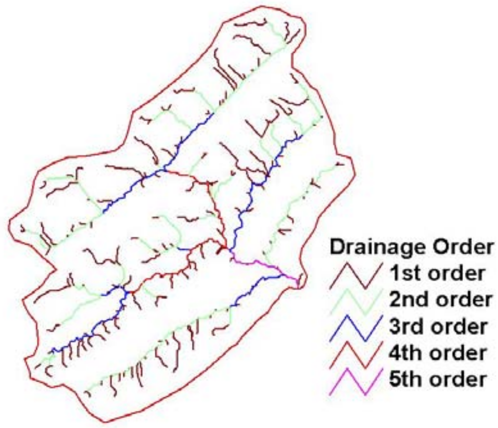

Fig. 7a Drainage Network extracted from 5m DEM

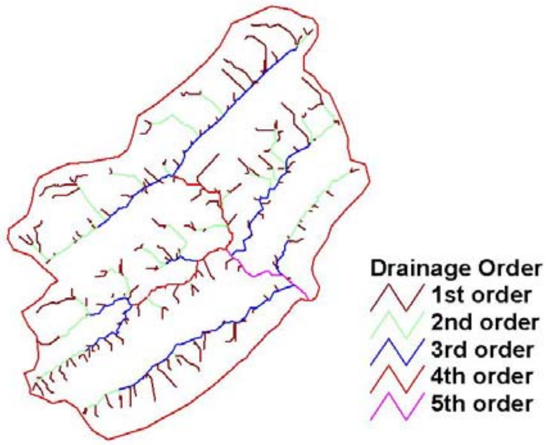

Fig. 7b Drainage Network extracted from 10m DEM

Drainage network has been extracted from standard procedures (Jenson and Domingue 1988) from DEM having resolutions 5m and 10m. The procedure includes generation of depression less DEM, computing flow directions, flow accumulation and delta value. The effect of DEM resolution on the drainage order was compared by automatically deriving the drainage order from the extracted drainages. Drainage network was generated from 5 & 10 m DEMs by taking similar area specific (5000 m^2) accumulation threshold for initiating the drainage on both DEM. The results are shown in figures 7a and 7b and Table 4.

Stream Order	Stream Number Derived from	
	5 m DEM	10 m DEM
1	198	190
2	34	30
3	8	7
4	2	2
5	1	1

Table 4. Comparison of Drainage Network Derived from 5 m and 10m DEM.

8. RESULTS AND DISCUSSION

The RPCs provides very good solution of ground coordinates with the help of a few GCPs. The accuracies can be improved using increasing the number of GCPs and order of the polynomial. Table 2 show the improvement in the RMSE at both Control and check points for different combinations of number of GCPs and polynomial order. When no GCP was used, the Check point accuracy at longitude, latitude and height were 22.6m, 98.4m and 22.9m respectively. This provides an estimation of the location accuracies using only RPCs provided along with data. By using a single GCP, RMS Error was reduced to the order of 10m in both planimetry and elevation.

Polynomial order 1 was used for RPC refinement process using 5, 8 and 10 GCPs. Similarly polynomial order 2 was used for 8 and 10 GCPs. The model accuracies provide very good results by changing the polynomial order from 1 to 2. RMS Error at check points were also reduced while using polynomial order and also for the increase in GCP number. Effect of increase in GCPs for polynomial order 1 from 5 to 10 shows an oscillatory behaviour. The results are positive for order two when GCP were increased from 8 to 10, where total RMSE at Check points is reduced. When 10 GCPs and polynomial order 2 were used for refinement of RPCs, RMSE at GCPs was minimum. The same effect was not exactly reflected in Check points probably because of the exact point identification on hilly terrain.

Table 3 shows the effect of DEM resolution in generating ortho image. The differences in latitude and longitude between ortho images generated from 5m DEM and 2.5m DEM is negligible. The differences are of the order of a meter in Longitude and 0.5m Latitude in respectively between ortho images derived from 10m DEM and 2.5m DEM.

Figures 5a and 5b reveals that the maximum slope are falling in the category of 15^0-25^0 and 25^0 - 40^0. The aspect analysis, as shown in Figures 6a and 6b, reveals that the maximum aspect are falling in the South and north direction.

Analysis of drainage network shows that there are not many differences in the number of higher order drainage. Only lower order drainages are getting affected by the DEM resolution size. As shown in table 4, there is a difference of 8, 4 and 1 in the number first order, second order and third order drainages respectively.

9. CONCLUSIONS

The model accuracies at GCPs and check points were derived, by changing the number and distribution of GCPs. The planimetric and vertical accuracies were respectively 4.3m, 3.5 and 3.1m in longitude, latitude and height by taking 10 GCPs and Polynomial order 2. There is an improvement in model accuracies also. The effect of DEM resolution on Ortho image accuracies show that enough care has to be taken in selecting DEM resolution while generating an ortho image. Mainly it depends on the type of applications in our hand. Terrain parameters such as slope, aspect, and drainage network were automatically extracted from DEM. Drainage network analysis shows the DEM resolution size affects the lower order drainages while varying the DEM resolution from 5m to 10m.

REFERENCES

Crespi M., F. Barbato, L.D. Vendictis, R.Onori, D. Polic, F.Volpe and X. Wang, 2006. Orientation, ortho-rectification, DSM extraction and 3D city modeling by Cartosat-1 stereo imagery: First results of a test over Rome. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Goa, India. Vol. XXXVI, Part-IVB, pp. 1020-1025.

Chen, L. C., T. A. Teo, and C. L. Liu, 2006. The geometrical comparison of RSM and RFM for FORMOSAT-2 satellite images. *Photogrammetric Engineering & Remote Sensing*, Vol. 72(5), pp. 573-579.

Dabrowski R., M. Kedzierski, W. Fedorowicz, R. Kaczynski and J. Zych, 2006. Geo-interpretation capabilities and precision of an ortho-photomap obtained from Cartosat images. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Goa, India. Vol. XXXVI, Part-IVB, pp. 1038-1040.

Di, K., R. Ma, and R., Li, 2003. Rational Functions and Potential for Rigorous Sensor Model Recovery. *Photogrammetric Engineering & Remote Sensing*, Vol. 69(1), pp. 33-41.

Fracer, C. S., and H. B. Hanley, 2005. Bias compensated RPCs for sensor orientation of High Resolution Satellite Imagery. *Photogrammetric Engineering & Remote Sensing*, Vol. 71(8), pp. 909-915.

Jeson, S. K., and J. O. Domingue, 1988. Extracting topographic structure from digital elevation data for geographic information system. *Photogrammetric Engineering & Remote Sensing*, Vol. 54(11), pp. 1593-1600.

Li. R, F. Zhou, X. Niu, and K. Di, 2007. Integrating of IKONOS and QuickBird imagery for geo-positioning accuracy analysis. *Photogrammetric Engineering & Remote Sensing*, Vol. 73(9), pp. 1067-1074.

Michalis P. and I. Dowman, 2006. Sensor model evaluation and DEM generation for Cartosat-1. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Goa, India. Vol. XXXVI, Part-IVB, pp. 1009-1013.

Nadeem, A, M. Anjum, A. Ritesh, P. Jayaprasad, S. K. Pathan, Ajai, D. K. Singh and A. K. Singh, 2007. Extraction and Validation of Cartosat-1 DEM. *Journal of the Indian Society of Remote Sensing*, Vol. 35(2), pp. 121-127.

Poon, J., C. S. Fracer, and C. Zhang, 2007. Digital Surface Models from High Resolution Satellite Imagery. *Photogrammetric Engineering & Remote Sensing*, Vol. 73 (11), pp. 1225-1232.

Rao B.S., A.S.R.K.V. Murali Mohan, K. Kalyanaraman and K. Radhakrishnan, 2006. Evaluation of Cartosat-1 Stereo Data of Rome. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Goa, India. Vol. XXXVI, Part-IVB, pp. 1026-1029.

Ritesh A., A. Nadeem, P. Jayaprasad, M. Anjum, J. A. Vinoth Kumar, S.K. Pathan and Ajai, 2006. Comparative evaluation of various algorithms for drainage extraction using Cartosat-1 stereo data. In: *Asia Pacific Remote Sensing Symposium* Goa, India. SPIE, Vol. 6411, 64110x.

Tao, C. V., and Y. Hu, 2001. A Comprehensive Study of the Rational Function Model for Photogrammetric Processing. *Photogrammetric Engineering & Remote Sensing*, Vol. 67 (12), pp. 1347-1357.

Tao, C. V., Y. Hu, and W. Jiang 2004. Photogrammetric exploitation of IKONOS Imagery for mapping applications. *International Journal of Remote Sensing*, Vol. 25 (14), pp. 2833-2853.

ACKNOWLEDGEMENTS

Authors express their sincere gratitude to Dr. R. R. Navalgund, Director, Space Applications Centre, Ahmedabad for his keen interest and guidance. Authors are thankful to Dr. J. S. Parihar, Deputy Director RESA, Dr. Manab Chakraborty, Group Director GTDG and Dr. Ajai, Group Director MESG, Space Applications Centre for their valuable suggestions during the study. Authors are extremely happy to acknowledge the help of Mrs. Anjum Mahtab, Scientist National Remote Sensing Agency, Hyderabad and Mr. Nadeem Ahmad, Nirma University, Ahmedabad during the execution of work.