ASSESSMENT OF GEO-POSITIONING ACCURACY ACHIEVED USING RATIONAL FUNCTION MODEL FOR CARTOSAT-1 STEREO DATA

Authors: Mrs. S S Palsule, Mr. G. Paswan, Mr. S S.S Kopparthi, Mr. Bankim Shah
Data Quality Evaluation Division, SIPG, RESIPA, Space Applications Center, ISRO, Ahmedabad-15, INDIA
shashi@ipdpg.gov.in, paswan@ipdpg.gov.in, sekhar@ipdpg.gov.in, bankim@ipdpg.gov.in

KEYWORDS: RPC, DEM, Orthokit, CARTOSAT-1, COTS, Orthoimage, GCP

Abstract:
Geo-referenced high-resolution satellite data product generated using CARTOSAT-1 stereo data can be used for mapping topographic information, navigation, urban planning. This paper present the first set of results of an assessment of geo-positioning accuracy achieved in image scan line and pixel number-to-Object space coordinates using system generated Rational Polynomial Coefficients (RPCs) of CARTOSAT-1 Stereo Orthokit Product. The computed object-space co-ordinates using Un-normalized space intersection model are compared with ground reference control points.
The CARTOSAT-1 system derived Rational Functional Model (RFM) is a replacement of rigorous sensor model of an image which represent set of co-efficients relating the geometric relationship of three dimensional object point position to their corresponding two dimensional image positions. The first exercise has shown that the system corrected RPCs have large systematic bias confirming to geo-product accuracy specification of 200m RMS in planimetry and average 20m in height. The same exercise has been further extended with the help of 2-3 precise GCPs for removing bias in Orthokit product and generating Orthoimage using ERDAS 9.0 (COTS) package. The Orthoimage product accuracy has been assessed.

1.0 INTRODUCTION

CARTOSAT-1 was launched on 5th May 2005, which is carrying mainly two panchromatic camera payload with +26 deg (FORE) and –5 deg (AFT) tilted with respect to nadir direction to generate along track stereo pair. This payload configuration will image the area with enhanced spatial resolution of 2.5 meter and 26 Km swath with along track stereo imaging capability, which has fixed Base to Height Ratio ensuring constant height resolution. This mission is for the Cartographic applications
Photogrammetric processing generally includes different processes like 3D reconstruction, Orthorectification and DEM generation. To perform these, the sensor model parameters are also required along with the satellite imagery. A sensor model relates three dimensional object point positions to their corresponding two dimensional image positions. It describes the geometric relationships between the image space and the object space.
The two broad categories of sensor models used are the physical sensor model and the generalized sensor model. A rigorous sensor model of an image is used to reconstruct the physical imaging setting and transformations between the object space and the image space. It includes physical parameters about the camera such as focal length, principal point location, pixel size, lens distortions and orientation parameters of the image such as satellite position and attitude values of sensor while acquiring the image. Collinearity conditions are the equations that are most popularly used to implement the transformations based on the rigorous sensor model. On the other hand, the generalized sensor model is used as a replacement for the rigorous sensor model. The generalized model parameters do not carry physical meaning of imaging process and it is sensor independent. Using the replacement sensor model, the photogrammetric processing can be performed without the necessity of the rigorous physical sensor model, the sensor type and the physical imaging process. To be able to replace the rigorous sensor model, the physical sensor model is often used for the determination of the unknown coefficients in the replacement sensor model.
The three main replacement sensor models are the Grid Interpolation Model, the Rational Function Model and the Universal Real Time Sensor Model. At present, the Rational Function Model is implemented to perform the 3D Reconstruction. In this model, the geometric relationships between the stereo images and the ground points can be approximately described by simplified polynomials, unlike the collinearity equations as used in rigorous sensor model.
The Cartosat-1 satellite uses the Push-broom scanning principle to obtain the imagery. For the images captured using this mechanism, the position of the projecting centers is a time – dependent function. The polynomial model is more suitable for this type of functions when compared to collinearity equations. The distortions caused by the optical projection can generally be represented by the ratios of first order terms, while the corrections such as Earth curvature, atmospheric refraction, lens distortion, etc. can be well approximated by second order terms. Some other unknown distortions with high-order components, such as camera vibration, can be modeled with the third order term. To take all this distortions into consideration the Rational Function Model is implemented using third order polynomial.
The Rational Function Model has become more popular as it has the capability to perform most of the photogrammetric processing including 3D reconstruction, Ortho-rectification, and DEM generation with an absence of the rigorous sensor model. The RFM facilitates the applications of high-resolution satellite imagery due to its simplicity and generality. Rational functions supply the data to the user without disclosing the sensor information. The rational Functions are sensitive to the distribution of Ground Control Points (GCP). The absolute accuracy of three-dimensional ground point determination or geo-positioning using the RFM depends on the accuracy of the actual rigorous sensor model itself.

The RFM Based 3D reconstruction has been implemented in some softcopy photogrammetric software package without disclosing the method. The in-house developed package RPC3D-GEO using Forward RFM has tested where the planimatric coordinates with ground elevation are represented as rational function of the image coordinates and this representation is used to establish 3D reconstruction.

2.0 OBJECTIVE

The main objective is development and testing of the package to compute the three-dimensional object space coordinates by using the Rational Function Model and compare them with precise ground measured GCPs. The algorithm is developed using C programming language. This paper highlights the mathematical formulation and algorithm developed for the computation of three-dimensional ground coordinates using unnormalized space intersection model. The test results are discussed.

3.0 DATA USED

The detail of CARTOSAT-1 data used is given in Table-1.

Sr. No.	Type of Product	Date of Pass	Path/ Row	Terrain Type
1	Stereo Orthokit	04 – Jan-2006	509 / 290	Plain
2	Stereo Orthokit	04 – Nov-2005	523 / 270	Hilly

Table: 1

Stereo Orthokit Product

CARTOSAT-1 Stereo Orthokit product provides the encrypted RPCs along with radiometrically corrected images in Geo-tiff format. These RPCs are directly used for the photogrammetric processing. It contains eighty coefficients and ten values of scale and offset for normalizing the image and ground coordinates.

4.0 BACKGROUND

The Cartosat-1 satellite uses the Push-broom scanning technique. The push-broom sensor is a linear sensing array associated with an optical system. The orbital motion of the satellite forms an image by generating each scan line with integration time. Each linear array has a set of six parameters. The stable orbit of the satellite gives, the position parameters (X,Y,Z) and the orientation parameters (omega, phi, kappa), which can be modeled by varying time. In three-dimensional visual depth perception both the monocular and binocular characteristics are used to determine the depth and size of the objects. The two binocular cues used in space perception are " the Convergence Angles of the optical axes of the eyes" and "Retinal Disparity". The concept of focusing accommodation of the individual eye is on of the important characteristics of monocular vision. The methodology of multi camera involves identifying and measuring homologues targets and patterns on the images of an object which had been identified different imaging view points.

Rational Polynomial Camera (RPC) Model:

The Rational Polynomial Camera Model relates the three-dimensional object space to the two-dimensional image space. The Rational Polynomial Coefficients can model reasonably complex transformations and can remain stable. A rational polynomial is a three-dimension to two-dimension transformation in the sense that a ground X, Y, Z are used along with the coefficients to compute image scan line and pixel values. A single image involves two rational polynomials, one for computing scan line position and one for the pixel position. The rational polynomial coefficients for a particular satellite image are computed using the data on the orbital position and orientation of the satellite sensor. The usual procedure for the RPC determination involves using the physical camera model to generate a three-dimensional grid of points, followed by least squares estimation of the coefficient values to fit this grid. The quality of the least squares fit depends on a number of factors, including view geometry, satellite dynamics during image capture, image strip length, range of heights used in the grid and the spacing of grid points. The primary purpose of using RPC is that it provides a common framework independent of the actual sensor used.

5.0 MATHEMATICAL FORMULATION

5.1 Rational Function Models

The image pixel coordinates (s, p) are expressed as the ratios of polynomials of object point coordinates (X, Y, Z) in the Rational Function Model. The ratio of polynomials defined for the Ground to Image transformation is called the Forward form or the upward form, given by the following equations.

$$s = \frac{P_1(X,Y,Z)}{P_2(X,Y,Z)}$$

$$p = \frac{P_3(X,Y,Z)}{P_4(X,Y,Z)} \qquad (1)$$

for the third case the numerator and denominator in equation 1 are 20 -term polynomial i.e,

$$P = \sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} a_{ijk} X^i Y^j Z^k = a_1 + a_2Y + a_3X + a_4Z + a_5YX + a_6YZ + a_7XZ + a_8Y^2 + a_9X^2 + a_{10}Z^2 + a_{11}XYZ + a_{12}Y^3 + a_{13}YX^2 + a_{14}YZ^2 + a_{15}Y^2X + a_{16}X^3 + a_{17}XZ^2 + a_{18}Y^2Z + a_{19}X^2Z + a_{20}Z^3$$

Where the $\mathbf{a_{ijk}}$ are the polynomial coefficients called the rational function coefficients (RPC), m1,m2 and m3 are maximum power of ground coordinates and are typically limited to three. (s, p) and (X, Y, Z) are the normalized image and ground coordinates respectively

5.2 Normalized Coordinates Relation:

Scan line, pixel from the image and three object point coordinates are each offset and scaled to fit the range from –1.0 to +1.0 over an image or image section in order to minimize the introduction of errors during the computation. The common normalized coordinate relation is given by

$$\text{Normalized value(N)} = \frac{(\text{Actual value(A)} - \text{Offset value})}{\text{Scale value}} \qquad (2)$$

In the above equation, Offset value = Average value
Scale value = max (|min – Average|, |max – Average|).

Hence the normalized Image coordinates are given by

$$\text{Scan Line (N)} = \frac{\text{(Scan Line (A) - Scan LineOffset)}}{\text{Scan Line Scale}}$$

$$\text{Pixel (N)} = \frac{\text{(Pixel (A) - Pixel Offset)}}{\text{Pixel Scale}}$$

and the normalized ground coordinate relation is as follows.

$$\text{Latitude value (N)} = \frac{\text{(Latitude (A) - LatitudeOffset)}}{\text{Latitude Scale}}$$

$$\text{Longitude value (N)} = \frac{\text{(Longitude(A) - LongitudeOffset)}}{\text{LongitudeScale}}$$

$$\text{Height value (N)} = \frac{\text{(Height (A) - HeightOffset)}}{\text{Height Scale}}$$

5.3 Linearization of Polynomial Functions:

The functions f_s and f_p defined from equations 1 that relate the image and ground coordinates are as follows.

$$f_S = s - \frac{P_1(X_u, Y_u, Z_u)}{P_2(X_u, Y_u, Z_u)}$$

$$f_p = p - \frac{P_3(X_u, Y_u, Z_u)}{P_4(X_u, Y_u, Z_u)} \qquad (3)$$

Here, s and p are the normalized image coordinates and X_u, Y_u, Z_u are the unnormalized object coordinates.
To determine the three dimensional ground points, the function should be linearized in the process of solving a third order non-linear equation. The linearization is performed using the Taylor series expansion. The linearized form of Equation 1 is given below.

$$\frac{\partial fs}{\partial X_u}\Delta X_u + \frac{\partial f_s}{\partial Y_u}\Delta Y_u + \frac{\partial f_s}{\partial Z_u}\Delta Z_u = -f_s \mid initial\_condition$$

$$\frac{\partial f_p}{\partial X_u}\Delta X_u + \frac{\partial f_p}{\partial Y_u}\Delta Y_u + \frac{\partial f_p}{\partial Z_u}\Delta Z_u = -f_p \mid initial\_condition \qquad (4)$$

$$\frac{\partial fs}{\partial X_u} = \frac{\frac{\partial P_1}{\partial X_u}P_2 - \frac{\partial P_2}{\partial X_u}P_1}{P_2{}^2}$$

$$\frac{\partial fs}{\partial Y_u} = \frac{\frac{\partial P_1}{\partial Y_u}P_2 - \frac{\partial P_2}{\partial Y_u}P_1}{P_2{}^2}$$

$$\frac{\partial fs}{\partial Z_u} = \frac{\frac{\partial P_1}{\partial Z_u}P_2 - \frac{\partial P_2}{\partial Z_u}P_1}{P_2{}^2} \qquad (5)$$

and $\frac{\partial f_p}{\partial X_u}, \frac{\partial f_p}{\partial Y_u}, \frac{\partial f_p}{\partial Z_u}$ can also be expressed in the same way.

$$\frac{\partial P_1}{\partial X_u} = (a_3 + a_5\,Y + a_7\,Z + 2\,a_9\,X + a_{11}\,YZ + 2\,a_{13}\,YX + a_{13}\,Y^2 + 3a_{16}\,X^2 + c_{17}\,Z^2 + 2\,a_{19}\,X\,Z\,)\,/\,Xs \qquad (6)$$

Similarly $\frac{\partial P_1}{\partial Y_u}, \frac{\partial P_1}{\partial Z_u}$ can also be expressed in the same way.

$$X = \frac{(X_u - X_0)}{Xs},\ Y = \frac{(Y_u - Y_0)}{Y_S},\ Z = \frac{(Z_u - Z_0)}{Zs}$$

All the remaining derivatives i.e. $\frac{\partial P_2}{\partial X_u}$, $\frac{\partial P_2}{\partial Y_u}$ and $\frac{\partial P_2}{\partial Z_u}$ are computed in the similar manner. The notations X_s, Y_s, Z_s are for scale and X_o, Y_o, Z_o for the offset values of ground point coordinates available from RPC file along with the orthokit product. The values of the terms in equation (5) can be obtained by substituting the value of the derivative from (6). Similar set of equations can be formed by the function defined in pixel equation defined in 3). This set of equation can also be obtained by corresponding image points in other image. Hence a system of four equations with three unknowns is being formed.

5.4 Slope and Offset:
The slope and offset are calculated by taking the maximum and minimum height and the Δ_{Zu} values obtained in the iteration.

5.5 Initial Approximation Determination Methods:
Computation requires the estimation of the three-dimensional ground coordinates initial approximate values of these ground coordinates, which could be determined with one of the following method.

I. The central values of Latitude, Longitude and Height can be calculated using the information given along with the Rational Polynomial Coefficients and these values can be passed as the initial approximations into the model to compute the actual ground coordinates.
II. Using the Ground to Image model given in equations (1), the partial derivatives with respect to latitude (X) and longitude (Y) are obtained by considering height (Z) as a constant value. The values of the partial derivatives are calculated using the central values of latitude, longitude and height and the matrix formed by two equations and two unknowns is solved to determine ΔX, ΔY. This procedure is repeated for the same point in the other image. The average of the results obtained is taken as the initial approximation values for latitude (X) and longitude (Y).
III. Considering only the first order terms of equation (1) for the identified point in both the images and partial differentiating them with respect to latitude, longitude and height, a design matrix can be formed. Solving this matrix using the least squares adjustment model is the initial approximate values of latitude, longitude and height by iteration.

5.6 Space Intersection:

Space Intersection is the process of photogrammetrically determining the spatial position of ground points by intersecting image rays from two or more images. The spatial direction of each image ray is determined by projecting the ray from the front nodal point of the camera lens through the image on the positive photograph. Conjugate image rays projected from two or more overlapping photographs intersect at the common ground points to determine the three-dimensional space coordinates of each point. The entire assembly of image rays is fit to known ground control points in an adjustment process, mostly the least squares adjustment process. Thus when the adjustment is complete, ground coordinates of unknown ground point are determined by the intersection of adjusted image rays. The process of space intersection is illustrated in Figure1.

In the diagram shown L_1, L_2 are the image exposure centers, O_1,O_2 are the perspective centers, a_1 and a_2 are the image positions in the two images corresponding to the same ground location A and X_A, Y_A, Z_A are the object space coordinates of the point A.

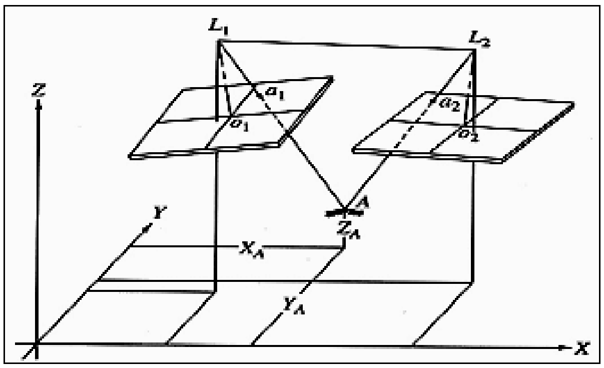

Figure1: Space Intersection

6.0 METHODOLOGY

6.1 3D Reconstruction with RFM model

The stereo Orthokit product contains the RPC file having eighty coefficients of third order polynomial along with ten values of scale and offset for normalizing the image and ground point coordinates. The procedure for determination of un-normalized 3D object point coordinates by forward RFM from a pair of conjugate points identified on FORE and AFT images are as follows

- **i** Normalize the image pair coordinates with scale and offset supplied with RPC
- **ii** Determination of initial approximation values of un-normalized object coordinates with first order polynomial keeping second and third order term as zero.
- **iii** Computation of partial derivatives of the function defined in equation (5) based on initial approximation defined in step–(ii)
- **iv** Formation of design matrix with the partial derivative values of the function with respect to un-normalized object point coordinates.
- **v** Calculate the correction for the initial approximation using the least square adjustment technique.
- **vi** Apply the corrections to initial approximations.
- **vii** Repeat the steps from iii to vi until the specified number of iterations has been reached or the corrections is less then set threshold ($1.2X10^{-11}$)
- **viii** The final computed values of un-normalized object point coordinates are compared with actual ground point coordinates.

6.2 Generation of Orthoimage

The Rational polynomial method is now fully ported into ERDAS 9.0 software for the Cartosat-1 data. The software supports the reading of satellite data, metadata, GCP and tie points' collection, orthorectification and mosaicking, stereo-model computation, image matching and DEM generation with automatic editing. After the stereo-model (RFM model) is computed using a minimum of 3 GCPs, an automated image matching procedure is used through a comparison of the respective grey values of the images. This procedure utilizes a hierarchical sub-pixel normalized cross correlation matching method to find the corresponding pixels in the left and right quasi-epipolar images. The difference in location between the images gives the disparity or parallax arising from the terrain relief, which is converted to X, Y, Z map co-ordinates using a 3D space intersection solution. Automatic and 3D-manual editing tools are finally used to improve DEM quality and coherency.

6.3 Evaluation of the 3D Reconstruction Models and Orthoimage

In order to assess the appropriateness of the models and the orthoimage, Check Points are used, which are not used for estimating the transformation parameters in the adjustment. Differences between calculated and known coordinates of the Check Points are the basis for the root mean square error (RMSE). Procedure for computation of RPC based scan line /pixel in image plane given in reference 4

7.0 RESULTS AND DISCUSSIONS

The Stereo Orthokit product for Ahmedabad (plain) region with relief variation from 30 meters to 60 meters and Alwar (hilly) region with relief variation from 200 meters to 700 meters has been evaluated for

a) Comparison of RPC based scan line, pixel and actual scan line, pixel of GCPs in image plane
b) Comparison of geodetic 3D reconstructed coordinate with actual geodetic 3Dcoordinates of GCPs on object plane

The available GCP coordinates for Ahmedabad area is used for evaluation using stereo Orthokit. For FORE camera the difference of RPC based computed scan line and actual scan line is within 1 scan lines and the difference of RPC based computed pixel and actual pixel is within 20 pixels. For AFT camera the difference of RPC based computed scan line and actual scan line is within 2 scan line & the difference of RPC based computed pixel and actual pixel is within 4 pixels The differences of scan line and pixel in meters for Ahmedabad area is given in Table-2.

Same GCPs are used for computation of reconstructed 3D geodetic coordinates. The difference is computed using first-degree polynomial as initial approximation and unnormalized space intersection model. The RPCs supplied in Orthokit product has been used to determine the three-dimensional coordinates using conjugate points. The RMS difference is observed as 21 meters and 17 meters in latitude and longitude direction respectively. The RMS of difference observed in height is 1.8 meters. The detailed results are given in Table-3.

Similar exercise was carried out for Alwar area, which is hilly in nature, using stereo Orthokit. For FORE camera the difference of RPC based computed scan line and actual scan line is within 40 lines & the difference of RPC based computed pixel and actual pixel is within 6 pixels. For AFT camera the difference of RPC based computed scan line and actual scan line is within 32 lines & the difference of RPC based computed pixel and actual pixel is within 4 pixels The differences of scan line and pixel in meters for Alwar area is given in Table-4.

Same GCPs are used for computation of reconstructed 3D geodetic coordinates. The difference is computed using first-degree polynomial as initial approximation and unnormalized space intersection model. The RPCs supplied in Orthokit product has been used to determine the three-dimensional coordinates using conjugate points. The RMS of difference is 92 meters and 21 meters in latitude and longitude direction respectively. The RMS of difference observed in height is 31 meters. The detailed results are given in Table-5.

The geo-position accuracy derived from scans line; pixel differences for Orthokit products are give in Table-6. The results are as per specifications.

The Alwar stereo Orthokit was further processed for Orthoimage generation using ERDAS COTS package. The geo-positioning accuracy of Orthoimage is within 15 meters. The Orthokit and Orthoimage geo-positioning accuracy comparison has been given in Table-7.

Detail results of difference of RPC based computed scan line, pixel and actual GCP scan line, pixel in meters			
Fore		Aft	
Diff_lat	Diff_lon	Diff_lat	Diff_lon
0.90	51.30	1.02	4.22
4.60	59.60	5.02	11.32
-2.00	58.10	-2.00	10.12
0.20	52.00	-2.20	7.72
Rms: 2.54	55.37	2.96	8.77
Std. Dev: 2.74	4.21	3.37	3.13

Table: 2 Detail results for Ahmedabad scene

Detail results of difference of reconstructed 3D coordinates and actual 3D coordinates			
Sr No	Diff_lat	Diff_lon	Diff_height
	mts	mts	mts
1	38.8	-22.6	1.0
2	-19.0	16.5	1.4
3	5.2	-11.6	1.3
4	4.6	-17.7	-3.0
Rms:	21.86	17.5	1.8
St. Dev.:	20.58	15.12	1.8

Table: 3 Detail results for Ahmedabad scene

Detail results of difference of RPC based computed scan line, pixel and actual GCP scan line, pixel in meters			
Fore		Aft	
AL	AX	AL	AX
100.5	-5.75	87.75	11.75
100.25	-10.25	93.75	15.75
107.5	-16.5	94.25	7.75
104.5	-12.75	96.25	11.25
99.00	-9.00	88.25	17.50
118.25	-9.50	76.25	-11.5
104.75	-12.5	85.5	11.75
101.5	-10.0	94.5	10.50
105.00	-22.00	86.25	-3.50
112.25	-11.50	90.75	8.75
87.75	-19.50	88.25	2.25
85.50	-4.25	86.5	8.50
103.75	-17.75	88.75	5.25
Rms: 102.7	13.4	89.6	10.3
St. Dev: 8.4	5.0	5.0	7.3

Table: 4 Detail results for Alwar scene

Detail results of difference of reconstructed 3D coordinates and actual 3D coordinates			
S. No	Diff_lat	Diff_lon	Diff_height
	mts	mts	mts
1	-92.95	-17.51	4.9
2	-94.88	-18.32	8.8
3	-115.67	-30.57	-73.5
4	-96.82	-22.26	12.0
5	-89.71	-15.67	18.1
6	-85.52	-18.89	39.7
7	-94.14	-20.58	14.4
8	-85.74	-27.43	0.1
9	-80.61	-15.52	23.5
10	-85.92	-25.34	37.6
Rms:	92.67	21.8	31.2
St. Dev.:	9.20	4.90	30.00

Table: 5 Detail results for Alwar scene

Area	FORE		AFT	
	Rms (mts)	Std (mts)	Rms (mts)	Std (mts)
	lat/long	lat/long	lat/long	lat/long
Alwar	102.70/ 13.40	8.40/ 5.00	89.60/ 10.30	5.00/ 7.30
Ahmedabad	2.54/ 55.37	2.74/ 4.21	2.96/ 3.37	8.77/ 3.13

Table: 6 Geo-location accuracy of Orthokit products

Comparison of geo-location accuracy for AFT camera over Alwar region		
Type of product	AFT	
	Rms (mts)	Std (mts)
	lat/long	lat/long
Orthokit	89.6 / 10.3	5.0 / 7.3
Orthoimage	16.7 / 11.8	4.9 / 5.3

Table: 7 Geo location accuracy comparisons

8.0 CONCLUSIONS

The first set of results of geo-positioning accuracy is compared based on actual ground control points which is limited by available GCPs. The scope of the exercise will be extended by increasing the density of conjugate points from stereo pair. Some of the conjugate points will correspond to ground control points.

The detail exercises in image plane where ground coordinates of points are converted in scan line, pixel using (RPC supplied in Orthokit) in-house developed 'RPC2DGEO' package and compared with actual scan line, pixel of GCP position. The other exercise in object plane where the actual scan line, pixel of GCP coordinate are passed into the RPC model package 'RPC3DGEO' (in-house developed) for reconstruction of latitude, longitude and height coordinates. These reconstructed coordinates are compared with actual ground coordinates. The geo-positioning accuracy in image plane and object plane are same for stereo Orthokit product and it meets the CARTOSAT-1 standard product specifications. The Alwar stereo Orthokit was further processed for Orthoimage generation using ERDAS 9.0 COTS package. The geo-positioning accuracy of Orthoimage is within 15 meters.

REFERENCES

1. 3D Reconstruction Methods Based on the Rational Function Model, PE&RS Vol. 68, No 7,July 2002, pp. 705-714
2. Li, R., 1998. Potential of High-Resolution Satellite Imagery for National Mapping Products. Photogrammetric Engineering and Remote Sensing, Vol. 64, No. 12, pp. 1165-1170.
3. Manual of Photogrammetry
4. Internal Technical documents of Data Products and Data Quality evaluation s/w systems

ACKNOWLEDGEMENTS

The authors wish to thank Dr. R. R. Navalgund, Director, SAC, Dr. K. L. Majumder, Deputy Director, RESIPA, Dr. P. K. Srivastava, Group Director, SIPG and Mr. A.S. Kiran Kumar, Group Director, EOSG for their encouragement for this activity. We are also grateful to Mr. T. P. Srinivasan, Scientist, SPDD/SIPG for all his valuable suggestion and discussion and Mr. S.S. Srivastava Scientist, DQED/SIPG for technical assistance.