DEVELOPMENT AND IMPLEMENTATION OF RATIONAL POLYNOMIAL COEFFICIENT ALGORITHMS FOR GEOREFERENCING CARTOSAT-1 DATA

S. Devika*, S.S.Ramakrishnan*, A.S.R.K.V. Murali Mohan** and B.Sadasiva Rao**

*Institute for Remote Sensing, Anna University -sdevika2002@yahoo.com
** Aerial Survey and Digital Mapping- National Remote Sensing Agency

ABSTRACT:

This particular study deals with the development of a Generic model called Rational Polynomial Coefficient, which relates the object space with the image space thereby, georeferencing a satellite image. For the purpose of georeferencing Cartosat-1 Leader file has been used. Ephemeris or the space positional coordinates and the attitude angles, which are a function of time, are extracted from the Leader file. The image coordinates and the corresponding ephemeris coordinates are used to derive the ground coordinates with the help of the physical model (Collinearity equation). The unknown Rational Polynomial Coefficients are obtained by developing a Rational function between the image row, column and the corresponding ground coordinates. From the calculated Rational Polynomial Coefficients, the ground coordinates are derived using the Rational Function. The geodetic height for the corresponding ground coordinates are input from the Shuttle Radar Topographic Mission 90 meter Digital Elevation Model. Then Root Mean Square Error is obtained between the calculated ground coordinates and those obtained by ground survey.

1. INTRODUCTION

An image taken from a satellite will have two types of distortion- radiometric distortion and geometric distortion. Radiometric distortion occurs due to the instrumentation error or the effect of the atmosphere on the pixel brightness value. Radiometric correction is usually carried out while preprocessing the satellite image and supplied to the user. Then it is necessary for the user to carry out the geometric correction for georeferencing the satellite image (Richards, J.A., and Xiuping Jia., 1999).The geometric distortion is the distortion of the image caused due to earth curvature (Fig. 1), earth rotation (Fig. 2), variation in altitude (Fig. 3) and attitudes pitch, roll, yaw (Fig. 4).
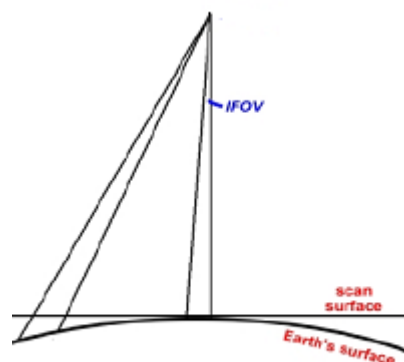

Figure 1. Distortion due to Earth curvature
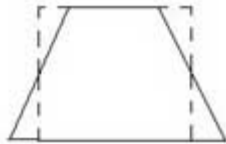
Figure 2. Distortion due to Earth Rotation

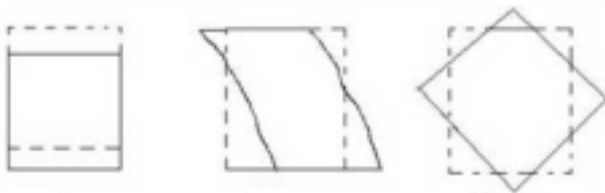Figure 3. Distortion due to variation in altitude

Figure 4. Distortion due to Pitch, Roll & Yaw

A satellite image has to be geometrically corrected after it has been radiometrically corrected especially if any interpretation, analysis or measurement has to be carried out. It would only then be possible to make proper measurement of distances, areas and accurate geographic locations. The image has to be geometrically registered to a known geographic base. Only then further analysis with other mapped data is possible.

1.1 Conventional methods for geometric rectification

- Image to ground rectification: The correction of digital images to ground coordinates using ground control points collected from ground using Global Positioning System.
- Image to map rectification: The correction of digital images to ground coordinates using ground control points collected from maps.
- Image to image rectification: The correction involves matching the coordinate systems or column and row coordinate systems of two digital images with one image acting as a

reference image and the other as the image to be rectified (Jensen, J.R., 1996).

1.2 Disadvantages of the conventional geometric rectification

- For the conventional geometric rectification it is required to carry out the spatial (Fig. 5) as well as intensity interpolation (Fig. 6) and also when mosaicing or combination of multiple images is carried out the spatial and intensity interpolation will become time consuming and strenuous.
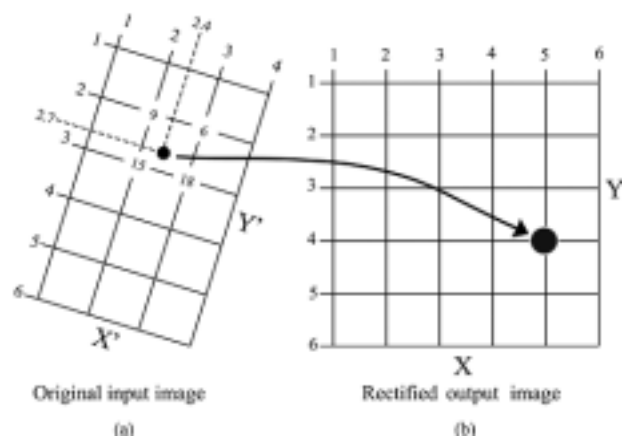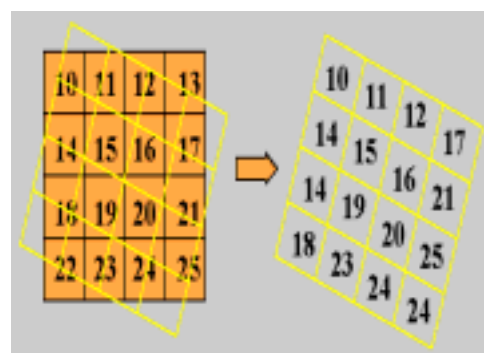

Figure 5. Spatial interpolation

Figure 6. Intensity interpolation

- Inorder to carry out mosaicing, the image is made to undergo 'warping' or 'rubber sheeting' (Fig. 7) where the original image is distorted so that the landmarks in the image are forced to the best fit (Fig. 8) of specified coordinates of the new image.
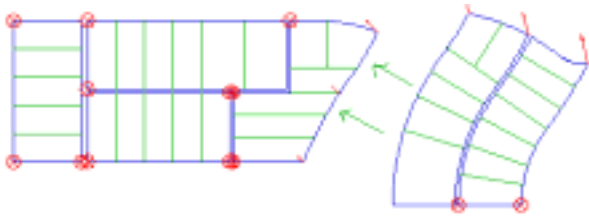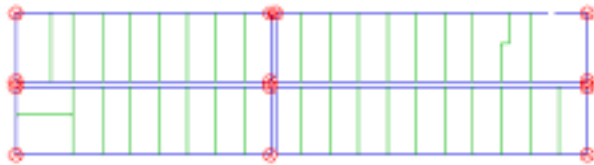
Figure 7. Rubber sheeting or Warping

Figure 8. New image after Rubber sheeting

- During mosaicing, brightness values in one scene will simply dominate the pixel values in the overlapping scene. Unfortunately, this can result in noticeable seams in the final mosaic. (Fig. 9)
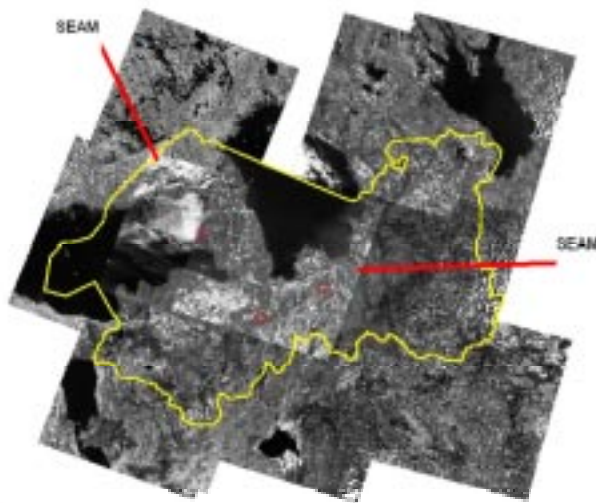

Figure 9. Noticeable seams in the mosaic

Thus to overcome these disadvantages two main types of sensor models are being used for geometric rectification; they are the Physical sensor model and the Generic sensor model.

Physical sensor model represents the real imaging process. To develop a Physical sensor model (Fig. 10) it is necessary to know the imaging parameters such as orbit parameters, sensor platform ephemeris data, relief displacement, Earth curvature, atmospheric refraction, lens distortion, etc. In physical sensor models, parameters are statistically uncorrelated as each parameter has a physical significance. Thus physical modelling becomes highly complex and also sensor dependent, that is different types of sensors need different models.
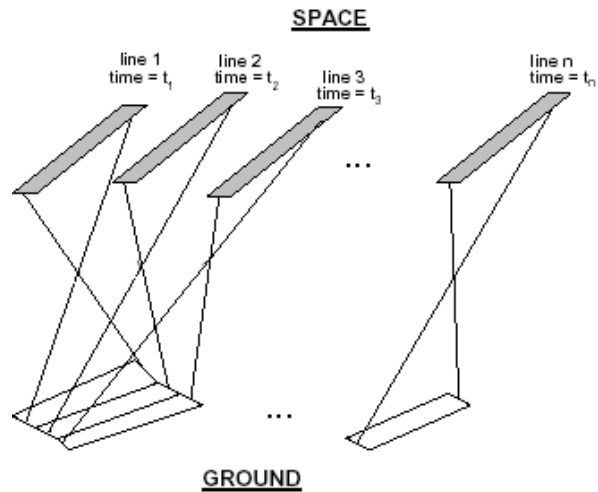

Figure 10. Physical sensor model
(Dial Gene and Grodecki, 2002)

With the increasing availability of new airborne and space-borne sensors, and wide use of different types of sensors such as Frame, Pushbroom, Whiskbroom, Panoramic, and Synthetic Aperture Radar, from an application point of view, it is not convenient for users to change the software or add new sensor models into their existing system for processing new sensor data. It has also been realised that Physical sensor models are not always available, especially for images from commercial satellites (e.g., IKONOS). Thus the Generic sensor models are used.

General models are the models, which require general functions to be implemented just once in software and any satellite image can be georeferenced. The general functions can be of several different forms of the rational polynomials of order one, two, three or more etc. In general, Generic sensor models do not require knowledge of the sensor geometry, thus they are applicable to different sensor types.

Generic sensor models are of two types, one that is dependent on the physical sensor model is called Rational Polynomial Terrain- Independent sensor model (Fig. 11) and the other one dependent on the actual terrain relief, the number of Ground Control Points and their distribution across the scene is called the Rational Polynomial Coefficient Terrain- Dependent sensor model.
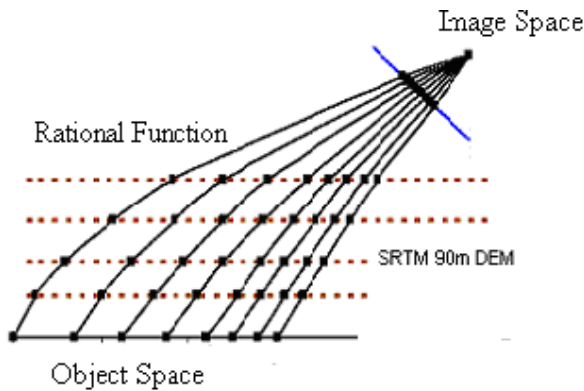

Figure 11. Rational Polynomial Terrain - Independent sensor model (Dolloff et al, 2004)

In this paper we deal with the Rational Polynomial Terrain Independent model.

1.3 Advantages of the RPC method

- It can be used in stereo reconstruction, Digital Elevation Model generation, Large scale mapping, Ortho-rectification, image registration etc. (Tao, C.V., 2001)
- The corrections can be applied irrespective of source and magnitude of distortion. (Richards, J.A., and Xiuping Jia., 1999).
- Irrespective of the sensor resolution and sensor type this method can be used.
- Georeferencing the image in any system (Geocentric, Geodetic etc.,) is possible.
- There is no need to carry out the spatial and intensity interpolation by rubbersheeting or by forcing the original image to the best fit of the specified coordinates in the new image.
- It performs georeferencing in less time and with less strain unlike the conventional methods.

This method of georeferencing can be used for any satellite image. Thus by implementing the RPC model once in software, the georeferencing can be carried out for any satellite image.

2. RATIONAL FUNCTION MODEL

2.1 Normalization:

The rn, cn, Xn, Yn, Zn where (rn, cn) are the normalised row (line) and column (sample) index of pixels in image space; Xn, Yn, and Zn are normalised longitude, latitude and geodetic height of object points in ground space. Normalisation results in each parameter to be offset and scaled to fit the range -1.0 to +1.0. It is essential to normalise the data prior to linear estimation to improve the numerical stability of the computation. (Kim et al., 2002, Tao, C.V., 2001)

$$X_n = \frac{X - X_{off}}{X_s} \qquad (1)$$

where

X = Longitude coordinate.
X_s = the scale value for Longitude
X_{off} = the offset value for Longitude

Similarly the offset for other ground coordinates and image coordinates are calculated.

2.2 The Rational Function:

$$r_n = \frac{p_1(X_n, Y_n, Z_n)}{p_2(X_n, Y_n, Z_n)} = \frac{\sum_{i=0}^{3} \sum_{j=0}^{i} \sum_{k=0}^{j} a_m X_n^{i-j} Y_n^{j-k} Z_n^{k}}{\sum_{i=0}^{3} \sum_{j=0}^{i} \sum_{k=0}^{j} b_m X_n^{i-j} Y_n^{j-k} Z_n^{k}} \qquad (2)$$

$$c_n = \frac{p_3(X, Y, Z)}{p_4(X, Y, Z)} = \frac{\sum_{i=0}^{3} \sum_{j=0}^{i} \sum_{k=0}^{j} c_m X_n^{i-j} Y_n^{j-k} Z_n^{k}}{\sum_{i=0}^{3} \sum_{j=0}^{i} \sum_{k=0}^{j} d_m X_n^{i-j} Y_n^{j-k} Z_n^{k}} \qquad (3)$$

where a_m, b_m, c_m, d_m = polynomial coefficients ($c_0 = 1$, $d_0 = 1$) are called RPCs.
p_1, p_2, p_3 and p_4 are polynomial functions.

r_n = normalised row
c_n = normalised column
X_n = normalised longitude
Y_n = normalised latitude
Z_n = normalised geodetic height.

$$m = \frac{i(i+1)(i+2)}{6} + \frac{j(j+1)}{2} + k \qquad (4)$$

2.3 Least Square Solution

The least square solution for the first order rational function is used to solve for the unknown rational polynomial coefficients given in the Equations (5) & (6)

$$A_{7x1} = M_{4x7}\, X_{4x1} \qquad (5)$$

$$A_{7x1} = (M^T_{\ 7x4}\, M_{4x7})^{-1}(M^T_{\ 7x4})\, X_{4x1} \qquad (6)$$

where

$$M = \begin{pmatrix} 1 & X_1 & Y_1 & Z_1 & -r_1X_1 & -r_1Y_1 & -r_1Z_1 \\ 1 & X_2 & Y_2 & Z_2 & -r_2X_2 & -r_2Y_2 & -r_2Z_2 \\ 1 & X_3 & Y_3 & Z_3 & -r_3X_3 & -r_3Y_3 & -r_3Z_3 \\ 1 & X_4 & Y_4 & Z_4 & -r_4X_4 & -r_4Y_4 & -r_4Z_4 \end{pmatrix}_{4x7} \quad (7)$$

$$A = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ b_1 \\ b_2 \\ b_3 \end{pmatrix}_{7x1} \qquad (8)$$

$$X = \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix}_{4x1} \qquad (9)$$

The least square solution for a general order rational function is given in equation (10)

$$A_{nx1} = \left(M^T_{nxm} M_{mxn}\right)^{-1} \left(M^T_{nxm}\right) X_{mx1} \qquad (10)$$

● The distortions caused by the optical projection can generally be represented by the ratios of first order terms.

● The corrections such as the curvature of the earth, atmospheric refraction can be approximated by the second order terms.

● Other unknown distortions can be modelled with the third order terms.

3. CARTOSAT-1 / IRS P5

Cartosat-1 is popularly known as IRS P5 as it belongs to the Indian Remote Sensing (IRS) series of the satellites. Cartosat-1 is a stereoscopic Earth observation satellite in a sun-synchronous orbit with a resolution of 2.5 m. The satellite was built, launched and maintained by the Indian Space Research Organisation. It was launched mainly for application of cartography in India. It was launched by the Polar Satellite Launch Vehicle on 5th May 2005 from the newly built second launch pad at Sriharikota.

The Cartosat-1 is configured with the Panchromatic cameras which are mounted such that one camera called the Fore camera is looking at +26° with respect to the nadir and the other called the Aft camera is looking at -5° with respect to the nadir along the track. These two cameras combinedly provide stereoscopic image pairs in the same pass. Also the whole spacecraft is steerable across track to provide wider coverage in a shorter period. The Orbit Specification of Cartosat-1 is given in Table 12.

S.No	Parameters	Specifications
01	Orbit	Polar Sun-synchronous
02	Orbital Altitude	618 km
03	Orbits/cycle	1867
06	Inclination	97.87°
07	Local time	10:30 A.M
08	Revisit	5 days
09	Repetition	126 days
10	Orbits/day	14
11	Orbital Period	97 minutes

Table 12. Cartosat-1 Orbit Specifications

3.1 CCD Arrangement in the cameras

There are two arrays each of 12000 Charge Coupled Devices (CCD) in each camera. The topmost array is an even arrangement of CCDs and the bottom array is an odd arrangement of CCDs. The arrangement of CCDs is shown in the figure. This type of arrangement is called a staggered arrangement of odd and even elements. The topmost array consists of even elements numbered -5998, -5996, -5994, -5992, -5990, -5988, -5986, ..., -2, 0, +2, +4, ..., +5998, +6000. The bottom array consists of odd elements numbered -5999, -5997, -5995, -5993, -5991, ..., -3, -1, +1, +3,....., +5993, +5995, +5997, +5999. The size of each CCD is 7mm x7mm. The distance between the two arrays is 35 mm. The distance between each CCD in each array is 7 mm. The focal length of the camera is 1945 mm.

Even though there are two arrays of CCD elements of 12000 each, still the type of arrangement is a linear type and not an area type. The reason why the staggered arrangement is made is so that no electronic cross-talk effect occurs on the adjacent pixels.

4. METHODOLOGY

This is a very simple Rational Polynomial Terrain Independent model developed with the available data, Leader file and the Shuttle Radar Topographic Model 90metre Digital Elevation Model (SRTM 90m DEM). The satellite image is thus georeferenced using the Rational Function that relates the object space with the image space.

4.1 Data Input

The input data formats taken for developing this model are follows:

● Cartosat-1 Data products system generates digital video data in Digital Audio Tape, Compact Disc-Read Only Memory and Digital Video Disc on the basis of user requests. Hence these products are referred to as Digital Product in general.Digital products are supplied in three formats such as a) LGSOWG (Landsat Ground Station Operators Working Group) or Super Structure Format, b) GeoTIFF, c) Fast Format. In this paper LGSOWG Format is only dealt with.

● In the LGSOWG, apart from the image data each digital product contains scene identification, location, sensor, platform and processing related information. This is a general digital data format, which is the same for all satellites after the launch of Landsat as its name suggests.

● The Cartosat-1 Leader file is composed of a file descriptor record and three types of data records. The record types are header, ancillary and annotation. Header contains information related to mission, sensor and processing parameters. Ancillary records contain information related to ephemeris, attitude and Ground Control Points (GCPs) for image correction.

● SRTM 90m DEMs with a resolution of 90m at the equator, and provided in mosaiced 5° x 5° tiles for easy download and is used for getting the 'Z' value in this model. These are

available in both ArcInfo ASCII (American Standard Code for Information Interchange) and GeoTiff formats to facilitate their ease of use in a variety of image processing and Geographical Information System applications. The SRTM data is available as 3 arc second (approximately 90m resolution) DEMs. A 1 arc second data product was also produced, but is not available for all countries. All are produced from a seamless dataset to allow easy mosaicing.

4.2 Detailed Methodology

The detailed methodology for developing the RPC Terrain Independent model is given below:

● The Leader file is scanned and LGSOWG is referred for decrypting the file. By scanning, the Ephemeris and attitude parameters of Cartosat-1 are extracted from the Header record of the Leader file.

● The Physical model or the collinearity equation is used for obtaining the ground coordinates corresponding to the ephemeris coordinates and the image coordinates. The ephemeris coordinates are in the geocentric coordinate system so they are converted to the geodetic coordinates and the 'Z' value corresponding to the ground coordinates is taken from the SRTM 90m DEM. The ground coordinates are interpolated for 12000 x 12000 pixels of Cartosat-1 satellite image. (Fig. 13)

● The Rational Polynomial Coefficient is calculated from the Rational Function model by substituting the normalised row, column and ground coordinates where the 'Z' value is again obtained from the SRTM 90m DEM.

● The latitude and longitude of the ground coordinates are obtained by substituting normalised row and column of the pixel, 'Z' value and the Rational Polynomial Coefficients.

Thereby the Cartosat-1 data is georeferenced by the Rational Polynomial Terrain- Independent Sensor model (Fig. 14).
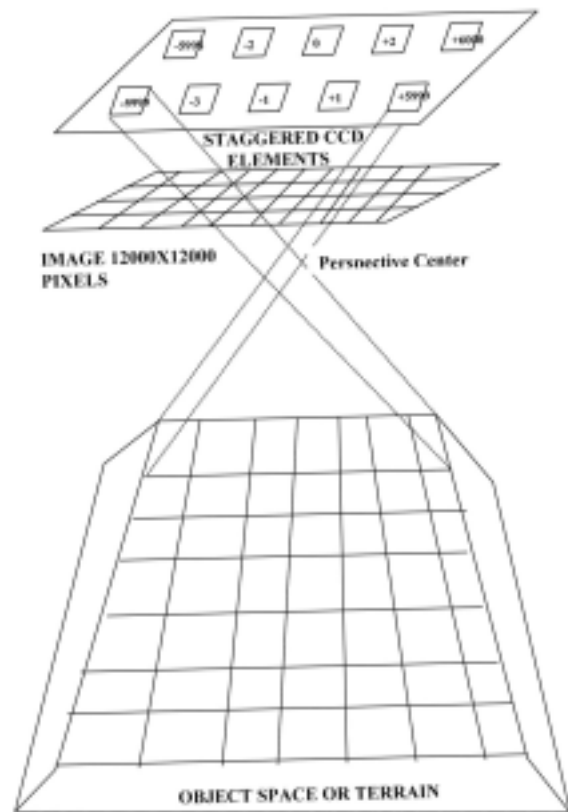

Figure 13. Relate object and image space using the Physical model
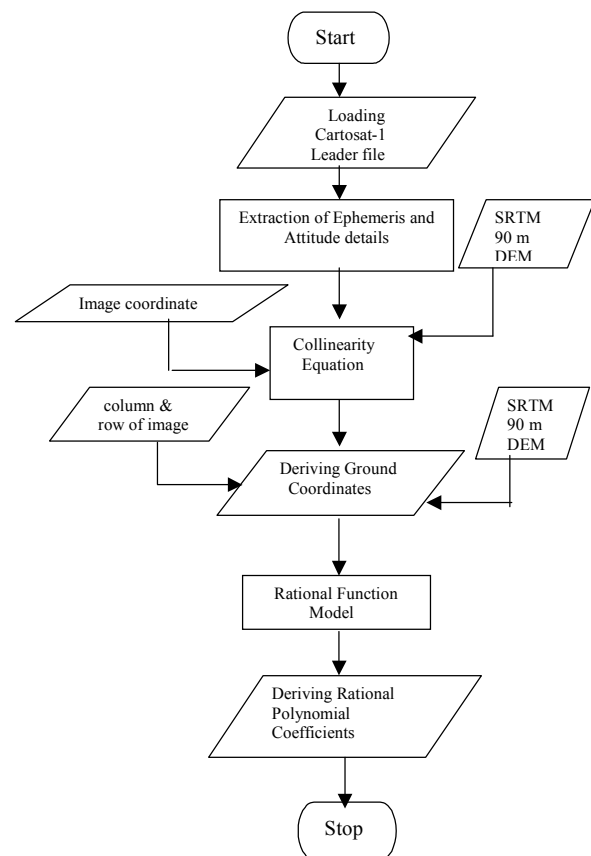

Figure 14. Methodology Flowchart

4.3 Validation

The actual ground coordinates (X_{actual}, Y_{actual}) are compared with the ground coordinates calculated ($X_{calculated}$, $Y_{calculated}$) from Rational Function and the Root Mean Square Error (RMSE) is determined by using Equation 11. (Fig 15)

$$RMSE = \sqrt{((\Sigma(Xresidual)^2 + \Sigma(Yresidual)^2/n)} \quad (11)$$

where, $X_{residual} = X_{actual} - X_{calculated}$
$Y_{residual} = Y_{actual} - Y_{calculated}$
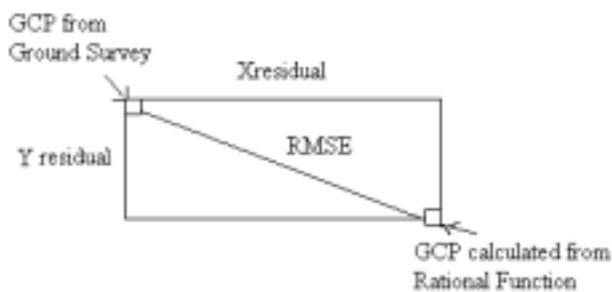n = number of Ground Control Points (GCPs)

Figure15.Diagrammatic representation of the RMSE

5. RESULTS AND DISCUSSION

In the global scenario, with the advancement in science and technology a large number of Remote Sensing satellites have been launched. A few of them have been listed below with their spatial resolution:

ENVISAT Medium Resolution Imaging Spectrometer (MERIS) 300m, Global Imager (GLI) onboard ADEOS II 1km, QuikSCAT 25km, MODIS (Moderate Resolution Imaging Spectroradiometer) onboard Terra satellite 250m, NOAA (National Oceanic & Atmospheric Administration) 1km, Landsat TM 30m, IKONOS PAN 1m and MSS 4m and QuickBird satellite with resolution of 0.62m etc.

India not to be left behind in the space technology has launched a number of remote sensing satellites.

India's first generation remote sensing satellites IRS-1A and 1B were designed, developed and launched successfully during 1988 and 1991 with multi-spectral cameras with spatial resolution of 72.5 m and 36 m. respectively. Subsequently, the second generation remote sensing satellites IRS-1C and 1D with improved spatial resolutions of 70 m in multi-spectral and 5.8 m in Panchromatic bands and a wide field sensor with 188m resolution and 800 km swath, have been developed and successfully launched in 1995 and 1997 respectively. These satellites have become the principal components in the National Natural Resource Management System and the data was used in various applications, viz., agriculture and soil, land form and land use studies, water resource, forestry, drought and flood monitoring, cartography, town planning and coastal zone monitoring.

IRS P6 or Resourcesat-1 as it is popularly called was launched in 2003. The LISS-IV camera can be operated either in panchromatic or multi spectral mode with a resolution of 5.8 m. LISS-III has a resolution of 23.5 m. AWifS has a resolution of 70 m. It is a follow-on satellite for earth observation to provide continuity of data to IRS-1C and 1D and will enhance the service capabilities in the areas of agriculture, disaster management, land and water resources with better resolution imagery.

IRS P4 or Oceansat-1, which was launched in 1999, carries on board an Ocean Colour Monitor (OCM) and a Multifrequency Scanning Microwave Radiometer (MSMR). OCM with a Field Of View of 360m is a solid-state camera operating in eight narrow spectral bands. The camera is used to collect data on chlorophyll concentration, detect and monitor phytoplankton blooms and obtain data on atmospheric aerosols and suspended sediments in the water. MSMR, which operates in four microwave frequencies both in vertical and horizontal polarisation is used to collect data on sea surface temperature, wind speed, cloud water content and water vapour content in the atmosphere above the ocean.

The recently launched IRS P5 or Cartosat-1 is an indigenous satellite with two improved 'Fore' and 'Aft' panchromatic stereo cameras with better than 2.5 m spatial resolution dedicated for large-scale mapping.

The satellites have different resolution and different types of sensors. For each sensor type (for e.g., pushbroom, frame sensor, Synthetic Aperture Radar, etc), there becomes a necessity to develop a new sensor model (for eg., Direct Linear Transformation, Projective transformation, 2D/3D polynomial model etc) (Tao V. and Hu Y., 2001) for relating the object space to the image space. This leads to complexity and difficulty for the user, since this will require different software for the implementation of each sensor model.

Nowadays the physical sensor details are not supplied with the satellites (e.g., IKONOS) inorder to prevent the satellites from being replicated. Thus it is not possible to go in for a physical sensor model, which requires the physical imaging details of the satellite.

Thus to describe the object-to-image relationship or to georeference the satellite image there is a need to have a model that can use general equations which are not dependent on the type of the sensors. The Generic sensor model that is being described in this paper is the RPC model that is mathematically a generic form of the models Direct Linear Transformation, Projective transformation, 2D/3D polynomial model etc.

The Cartosat-1 satellite image was thus georeferenced using RPCs and the necessary accuracy was achieved. The accuracy of the model can be improved by carrying out the following modifications.

- SRTM DEM has a 90m resolution while the resolution of Cartosat-1 is 2.5m. If an External DEM of higher resolution is used the accuracy may be improved. Since SRTM DEM is a freely downloadable DEM it has been used for an experimental purpose.

- As we know Cartosat-1 is a high resolution satellite so the Ephemeris/Attitude details that have been provided in the Leader file may not be an accurate one inorder to protect the satellite from being replicated and also for security reasons.

6. CONCLUSION

From the result obtained, we can conclude that this type of sensor model will be very useful in georeferencing low and medium resolution satellites like Oceansat-1 with a resolution of 360m, NOAA Advanced Very High Resolution Radiometer with a resolution of 1 km, MODIS onboard Terra with resolution of 250m, MERIS onborad ENVISAT with resolution of 300m, GLI onboard ADEOS II with a resolution of 1km etc. The SRTM 90m DEM data may be sufficient for georeferencing low and medium resolution. The Ephemeris/Attitude details also may not be as secure as they will be for high resolution satellites.

The low and medium resolution satellites can be used for land and atmospheric monitoring. They are used for the measurement of sea colour in oceans and coastal areas. Knowledge of sea colour can be converted into a measurement of chlorophyll pigment concentration, suspended sediment concentration and aerosol loads over marine areas. They observe globally and frequently the reflected solar radiation from the Earth's surface including land, ocean and clouds. These data may be used for determining the global circulation of carbon; monitoring clouds, snow, ice and sea surface temperature; and investigating the primary marine production. GLI also has an infrared radiation capability to measure the physical parameters such as chlorophyll, dissolved organic matter, surface temperature, vegetation distribution, vegetation biomass, distribution of snow and ice, and albedo of snow and ice. Thus these low and medium resolution satellites are useful in global and regional studies of land as well as ocean.

6.1 Future scope

Thus the future of georeferencing lies with the RPC modelling. All the satellite images are now being provided with RPCs. These RPCs are not only used for georeferencing they can be further used for stereo reconstruction, ortho-rectification, Large-scale mapping, image registration, etc.

Acknowledgements

References from Books

Jensen, J.R., 1996. Introductory Digital Image Processing-A Remote Sensing Perspective. Prentice-Hall, Inc.

Richards, J.A., and Xiuping Jia., 1999. Remote Sensing Digital Image analysis. An introduction. Springer-Verlag Berlin 1999

References from Websites

Croitoru Arie, Tao Vincent, Hu Yong and Xu Jeff, 2004. The Rational Function Model: A unified 2D and 3D spatial data generation scheme,ASPRS Manual. http://www.spatial.maine.edu/~croitoru/ Publications/croitoru_et_al_ASPRS_04.PDF

Dial Gene and Grodecki Jacek, 2002. "Block adjustment with Rational Polynomial Camera models",ACSM-ASPRS2002.Annual Conference proceedings. http://www.spaceimaging.com/whitepapers_pdfs/ 2002/Block%20Adjustmet%20with%20RPCs-ASPRS%202002.pdftion.ethbib.ethz.ch/ecol-pool/inkonf/inkonf_53.pdf

Dial Gene and Grodecki Jacek, 2004. "RPC Replacement Camera Models" Proceedings of ASPRS 2005 Conference, Baltimore, Maryland, March 7-11. 45 http://spaceimaging.com whitepapers_pdfs/2005/RPC%20Replacement %20Camera%20 Models%20 Final.pdf

Dolloff John, Taylor Charles, 2004. Replacement Sensor Model Tagged Record Extensions Specification for NITF 2.1, APPENDIX C, Draft 7/23/04, paper invited for the 2004 Manual of Photogrammetry. http://www.ismc.nima.mil/ntb/ coordinationitems RSM%20TRE%20Appendiix %20C_July_23_04.pdf

Image Processing and Analysis-Tutorial http://www.gisdevelopment.net/tutorials/ tuman005pf.htm

Kim, Hye-Jin Kim, Dae-Sung Lee, Hyo-Sung KIM and Young I.L., 2002. A Study on the Generation of the Kompsat-1 RPC Model, ISPRS. http://www.isprs.org/commission3/proceedings/ papers/paper129.pdf

Tao, C.V., 2001. A Comprehensive Study of the Rational Function Model for Photogrammetric Processing, PE&RS Vol.67, No.12, pp.1347-1357. http://www.geoict.yorku.ca/project/ rationalmapper/pers2001_rfm.pdf

Tao V. and Hu Y., 2001. Use of the rational function model for image rectification. CJRS, 27(6), pp. 593-602. http://www.geoict.yorku.ca/ project/rationalmapper/cjrs2001_rfm.pdf.

Tao V. and Hu Y., 2002. 3D reconstruction methods based on the rational function model, Photogrammetric Engineering & Remote Sensing, 68(7): 705-714. http://www.geoict.yorku.ca/project/ rationalmapper/ pers2002_rfm3D.pdf

References from Others

ISG Newsletter Volume 11, No.2 & 3, June & Sept. 2005.