SATELLITE DATA PREPROCESSING - NEW PERSPECTIVES

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ABSTRACT

In this paper different geometric rectification methods are analysed & compared. These methods are polynomial, affine & differential. It is argued that the differential rectification method, since it models the orbit/attitude and combines the GCPs in a simultaneous adjustment, is superior. The possibility of using configurations like strip, block, twin pair etc are also discussed. In the SAR preprocessing, it is pointed out that it has a definite role at the user/application level, so that data at different stages can be appropriately utilized.

1. Introduction

Precision corrected products are essential for applications of satellite imagery requiring high accuracy such as mapping, map updates and change detection. Such applications thus call for a special preprocessing procedure. Geometrically corrected satellite imagery can be used effectively for cartographic applications due to its key advantages which include data acquisition flexibility, high spatial resolution and stereoscopic capability. Recently, rectification methods have gained more significance due to the fact that digital maps are to be combined with digital imagery. To make sure that they are overlaid at the correct locations, both have to be related to the same datum (map projection). The mathematical models applied for this geometrical correction range from simple affine transformations, utilizing higher order polynomial and projective transformations to some complicated models with orbit attitude correction. The last method is of particular importance, if a surface model of the landscape has to be created.

In India, ADRIN, ISRO, NRSA and, in general, the Department of Space have experimented with SPOT and IRS images for updating topographic maps and some of the experimental results have been reported (Srivastava et.al). Mapping organisations like SOI are utilizing images for map updating tasks using analytical plotters.

This paper briefly review some of the widely used rectification techniques and tries to point out the advantages and set backs of each. Then we present the preprocessing techniques developed inhouse for different optical image configurations and also for SAR images. This rectification method is based on the orbit attitude correction making use of the ephemeris information. A number of papers have been published on different approaches in modelling the satellite image geometry (Dowman, 1991). These methods demand multiple controls for the correction. The requirement of highly accurate control is a major problem in remote areas, where satellite data is most useful for topographic mapping. It has therefore become necessary to reduce the control requirements to a minimum and with this aim, we have developed a model for updating the orbital parameters with a single GCP. In this model, a rigorous geometric reconstruction of spatial relations between image and ground scene, combining the principles of photogrammetric bundle formulations modified in a time-dependent mode, is derived from known orbital relations using a single GCP. Figure-1 outlines the processing steps in the hierarchical order. Processing of different image configurations like strip, twinstrip and block are explained.

2. Review of widely used rectification methods

Here, we will briefly review some classical geometric image rectification methods. The main geometric error in satellite imageries comes, mainly, from differences in image scales in the along and the cross-track directions in addition to non-perpendicularity between image-axes in these two directions. These are first-order errors and can be rectified by simple mathematical models such as two-dimensional affine transformation. Another second order geometrical errors resulted from altitude and attitude variations, can be partly modelled using polynomial transformations (Maarouf, 1992)

Polynomial rectification

For the second order polynomials, relaltionships between measured image coordinates (x, y), for an image point (i), and ground coordinates (E, N) for the same point may be expressed as

$$E_i = a_0 + a_1 x_i + a_2 y_i + a_3 x_i^2 + a_4 x_i y_i + a_5 y_i^2$$
$$N_i = b_0 + b_1 x_i + b_2 y_i + b_3 x_i^2 + b_4 x_i y_i + b_5 y_i^2$$

where a,b,c,d, are the transformation constants. This method corrects for distortions of the image relative to a dense set of control points. The order of the polynomial depend on the number of control points available. This approach is completely independent of the geometry of the imaging sensor. Due to the polynomial transform, the original image is shifted, rotated, scaled and squeezed, so that it fits best to the given reference points.

Although polynomials are very easy to use for rectifications, they can cause problems and errors in the transformed image. They do not adequately correct relief displacements, nor do they consider the special geometry of the imaging system. The biggest advantage of the polynomial transform is the fact that all distortions of the image due to sensor geometry, relief displacement, earth curvature, etc. are corrected simultaneously.

Two dimensional similarity transformation

For the 4 parameters, two dimensional, similarity transformation, relationships between measured image co-ordinates (x,y) for an image point (i), and ground coordinates (E,N) for the same point may be expressed as

$$\begin{vmatrix} E \\ N \end{vmatrix}_i = \begin{vmatrix} a & -b \\ b & a \end{vmatrix} \cdot \begin{vmatrix} x \\ y \end{vmatrix}_i + \begin{vmatrix} E_o \\ N_o \end{vmatrix}$$

where a,b, E_o, N_o are the constants

Affine Transformation

For 6 parameter two-dimensional affine transformation, the relationships are in the form:

$$\begin{vmatrix} E \\ N \end{vmatrix}_i = \begin{vmatrix} a & -b \\ c & d \end{vmatrix} \begin{vmatrix} x \\ y \end{vmatrix}_i + \begin{vmatrix} E_o \\ N_o \end{vmatrix}$$

A comparison table of the residuals obtained using the above methods in a SPOT scene are given below (collected from Maarouf, 1992)

Transformation models											
I N	IK	2D- Similarity		2 D-affine		Second order Polynomials 4 terms		5 terms		6 terms	
	RE	RN	RE	RN	RE	RN	RE	RN	RE	RN	RE
	2	89.9	51.5								
	3	77.5	42.7	96.9	57.0						
	4	68.6	45.7	45.6	46.3						
68	6	64.9	44.6	45.5	41.9	86.5	71.8	64.5	79.4	78.4	85.9
	10	64.9	45.8	47.2	41.0	63.7	40.3	76.0	45.2	76	77
	15	65.3	42.9	48.3	33.1	55.6	38.3	44	44	48	42
	20	76.5	43.0	50.4	32.2	62.4	33.1	46.8	34.5	43	44
	30	62.4	48.3	47.8	30.8	62.4	30.4	46	29	43	29
	68	62.1	40.7	42.2	29.6	42.2	29.1	33.8	33.28	33	28

Table Root mean square errors of residuals with different transformation models.

RE = Root mean square error in easing direction
RN = Root mean square error in northing direction
IN = Number of reference points,
IK = No. of check points.

3. Orbit attitude modelling approach

This is a differential rectification method. The term differential rectification has its origin in the approach of rectifying small parts of a photograph at a time. For digital differential rectification, each pixel is related to the object space through collinearity equations. The requirement for highly accurate control points is a major problem in remote areas where satellite data can be used for topographic mapping. It has therefore become necessary to reduce the control requirements to a minimum and with this aim, a model for updating the orbital parameters with a single GCP has been developed.

Mathematical Model

The basic model used is the collinearity condition. Each observation of a GCP will give rise to a set of two collinearity equations. These will be derived from the following relationship between the satellite position and the GCP in the geocetric system.

$$\overline{X} = \overline{P} + d \cdot \overline{u}$$

$\overline{X}$ = ground control point position vector
$\overline{u}$ = unit vector pointing from the satellite to the control point
d = scaling factor

using rotation matrices, the above equation can be expressed as

$$\overline{X} = P + d \, R_{GF} R_{FB} R_{BS} \, \overline{xs}$$

$\overline{xs}$ = vector in the sensor system to the detector imaging the control point.
R_{GF} = flight - geocentric transformation matrix
R_{FB} = body-flight transformationnn matrix
R_{BS} = sensor-body transformation matrix

$$\begin{vmatrix} o \\ gs \\ -f \end{vmatrix} = 1/d \begin{vmatrix} m11 & m12 & m13 \\ m21 & m22 & m23 \\ m31 & m32 & m33 \end{vmatrix} \begin{vmatrix} x - xp \\ y - yp \\ z - zp \end{vmatrix}$$

where $M = (R_{GF} \; R_{FB} \; R_{BS})^T$ rotation matrix to transform from geocentric to sensor co-ordinate system.

g_s = coordinate of the fractional detector position imaging the control point.

The set of orbital parameters to be updated using the above model are

i, inclination
Ω, right ascension of ascending node
ν, mean anomaly at time t_o
r, radius of the orbit at time $t = t_o$

The attitude parameters to be updated are

ω, roll
σ, pitch
κ, yaw

The rotation matrix is a function of all these parameters.

$\Omega(t) = \Omega_o + \Omega_1 t + \Delta\Omega_o$ $\qquad \omega(t) = \omega_o + \omega_1 t + \omega_2 t^2 + \omega_3 t^3 + \Delta\omega_o$
$i(t) = i_o + i_1 t + \Delta io$ $\qquad \phi(t) = \phi_o + \phi_1 t + \phi_2 t^2 + \phi_3 t^3 + \Delta\phi_o$
$\nu(t) = \nu + \nu_1 t + \Delta\nu o$ $\qquad \kappa(t) = \kappa_o + \kappa_1 t + \kappa_2 t^2 + \kappa_3 t^3 + \Delta\kappa_o$
$r(t) = r_o + r_1 t + r_2 t^2 + r_3 t^3 + \Delta r_o$

Δ = corrections to the approximate parameters.

The control point measurement will give rise to a measurement vector consisting of five observations; two co-ordinates from the raw image and three coordinates from the ground. The measurements and parameters are related by collinearity equations. We start with a set of estimated values where the orbit and attitude parameters are derived from the ephemeris. Linearized forms of the condition equations are developed using Taylor series expansion around the measurement and parameters and only first -order terms are retained. Then we go for a least squares solution to this system. Co-factor matrix for measurements and a weight matrix for parameter estimates are included in the adjustment process. The solution is properly iterated until it converges.

The processing steps in the hierarchical order are outlined in the figure below.

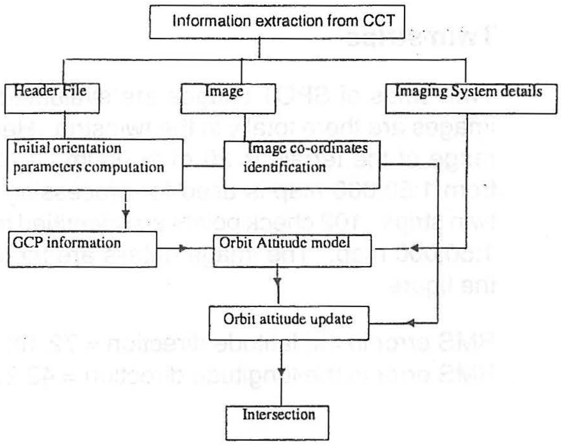

Fig.1 Processing Hierarchy

The above described modelling procedure for a single scene is extended for different image configurations like

a) strip
b) twin strips
c) block

This modelling approach has been tested for SPOT PLA and IRS-1C PAN images.

Strip Processing

The strip processing of satellite imagery is based on the fact that during one pass, the image data stream forms one single very long image. The geometry of this extended image can be rectified with as few control points as for only one scene if orbital constraints and attitude measurements are properly taken into consideration. This is an extension of the single scene adjustment described in the previous section.

Determination of overlap of imagery joins is made automatic using the image co-ordinates (fig 2). As the images of one strip have been registered continuously, the y coordinate of any point common to two images is the same. Identifying common points of two images and measuring their x coordinates in each of the two image coordinate systems allows the calculation of the overlap.

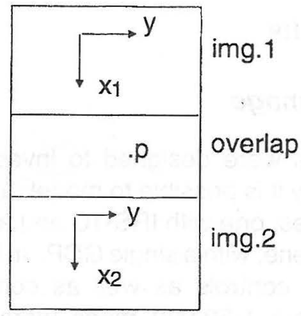

Fig. 2

Processing Twin Strips

Twin strips are a pair of strips acquired with a twin-instrument configuration. When both the instruments of SPOT satellite operate together in this configuration, the angular displacement between their respective viewing directions is 3.926 degrees. The offset between the two images is related to the distance between the two scene centers. Having understood the twin-pair acquisition geometry, the methodology of orbit attitude modelling have been accordingly modified. It is possible to take advantage of the fact that the ephemeris data stream from both the instruments in a twin pair configuration can be appended and they can be used as images in the same strip.

Block Processing

The control extension over a big block of images can be done using this modelling approach with a GCP in any one corner of the block. Using the available GCP, that strip will be processed first. Then a secondary control will be derived in the overlap area with the adjacent strip. Then that strip will be processed with the derived secondary control. This way, the whole block can be processed step by step. This method of control extension is very useful in inaccessible areas where there are no maps. In plane areas the accuracy will be high.

4. Results

Single Image

Two tests were designed to investigate how accurately it is possible to model the geometry of satellites, one with IRS-1C and another with SPOT scene, with a single GCP. In both cases, surveyed controls as well as controls/check points from 1:50,000 maps were evaluated separately. The marking of position of these points in the scene was made by manual pixel pointing with the cursor on the display. The results are as follows:

Test	Image details P/R	Date	Look angle	Source of control ht. range of terrain	No. of GCPs	No. of Check points	RMS(m) Lat	Lon
1. IRS-1C	100/60C9	11.4.96	-17.1	Surveyed /400-60m	1	5	8.7	7.8
				1:50,000 map / 400-60m	1	28	34.2	35.2
2. SPOT	206/290	02.11.90	7.03	Surveyed/200-300m	1	7	9.24	22.4
				1:50,000 map / 200-300m	1	21	25.2	39.2

Strip

Two sets were done to evaluate the accuracy of the model one with IRS-1C strip and another one with a SPOT strip. IRS-1C strip is having 3 images and SPOT strip have 5 images. Control and check points are from 1:50,000 map in the case of SPOT strip. In IRS-1C strip both surveyed controls as well as 1:50,000 map controls are evaluated separately. The results are as follows.

Test	Image details P/R	Date	Look angle	Source of control ht. range of terrain	No. of GCPs	No. of Check points	RMS(m) Lat	Lon
1. IRS-1C	100/60C9	11.4.96	-17.1	Surveyed/400-60m	1	8	9.3	5.3
	C3	"	"	1:50,000 map / 400-60m	1	44	26.5	43.4
	C6	"	"					
	C9	"	"					
2. SPOT	200/285	15.11.96	18-13	1:50,000 / 200-300m	1	67	64.4	59.0
	200/286	"	"					
	200/287	"	"					
	200/288	"	"					
	200/285	"	"					

Twin strips

Twin strips of SPOT images are evaluated. 9 images are there totally in the twinstrip. Height range of the terrain is 20 m to 900m. 1 GCP from 1:50,000 map is used for processing the twin strips. 102 check points are identified from 1:50,000 map. The image details are there in the figure.

RMS error in the latitude direction = 72.1m
RMS error in the longitude direction = 42.2m

Block

A block of 11 SPOT images is taken for the evaluation (see the figure 4). A GCP in 207/312 was used for modelling 207/312. All other scenes (/strips) are modelled using derived secondary controls. Height range of the terrain is 20m to 1300m. The ground coordinates computation RMS error in different areas of the block are as follows.

Scene / Strip	RMS (m) Latitude	Longitude
203/312 203/313	30.8m	105.2m
204/311 204/312	39.2m	64.4m
205/311 205/312	47.6m	30.8m
205/313 205/314	42.1m	53.2m
206/313	25.2m	64.4m

5. SAR Geocoding:

Conventional methods of rectification involves identification of GCPs on image and maps followed by registration. But these methods pose problems due to non-availability of GCPs particularly from SAR images and the difficulty in fitting a real surface accurately by the mathematical formulation. The approach adopted here uses satellite ephemeris data and exploits the SAR geometry of acquisition of image along with the Doppler informations. In case of ERS-1 SAR the post-facto ephemeris data are very accurate. The accuracy of ephemeris data from ERS-1 has been observed in the data products generated at ADRIN. The accuracies are reported by Roth [1]. The availability of accurate ephemeris data obviates the need for identification of GCPs. The geocoding procedure requires the SAR image in slant range format, which is an intermediate product in the preprocessing of SAR raw data. The method involves two transformations viz., map space to image space using object space image space modelling and image space to map space. In the first transformation a pixel is determined in the slant range image for a given Lat/Lon & height in the map. This algorithm is also termed as pixel location algorithm. It is achieved by use of doppler centroid and range equations, which are given below:

Doppler Equation:

$F_{dc} - 2.(\bar{p} - \bar{s}) . (\dot{\bar{p}} - \dot{\bar{s}}) / \lambda |\bar{p} - \bar{s}| = 0$

where,

Fdc - Doppler centroid

$\bar{p}, \bar{s}$ - Position vectors of observation point on Earth's surface and satellites position

$\dot{\bar{p}}, \dot{\bar{s}}$ - velocity vectors of observation point and satellites position

λ - Wavelength of the transmitted SAR signal

Range equation:

$r_o - m_r.j - |\bar{p} - \bar{s}| = 0$

ro - Slant range

m_r - Sampling range in range direction

j - pixel number in slant range image

Depending on the type of terrain undulations geocoding will be carried out in one of the two possible ways. In plain & moderately undulating terrain surfaces the earth surface is considered as an ellipsoid. The geocoded product generated by assuming earth as ellipsoidal surface is called Geocoded Ellipsoid Corrected (GEC) product. Whereas in highly undulating or hilly terrains DTMs (Digital Terrain Models) are used for terrain modelling and generated geocoded products are called Geocoded Terrain Corrected (GTC) product. The evaluation results of GEC products generated at ADRIN has showed RMS errors of 70m & 58m in Easting & Northing respectively [2].

Conclusions

This paper briefly reviews some of the widely used satellite image rectification methods and tries to point out the advantages and setbacks of each. Then we present an orbit attitude modelling approach with which we can rectify different image configurations like strip, twin strip, block etc. with a single GCP. We also explain a preprocessing method for SAR images. We present the results obtained from different image configuration with controls from different sources. The obtained results indicate that a single surveyed GCP is enough to obtain the accuracy equal to the resolution of the sensor. Attainable geometric accuracy will increase as point identification and detectability is increased.

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TWIN STRIPS

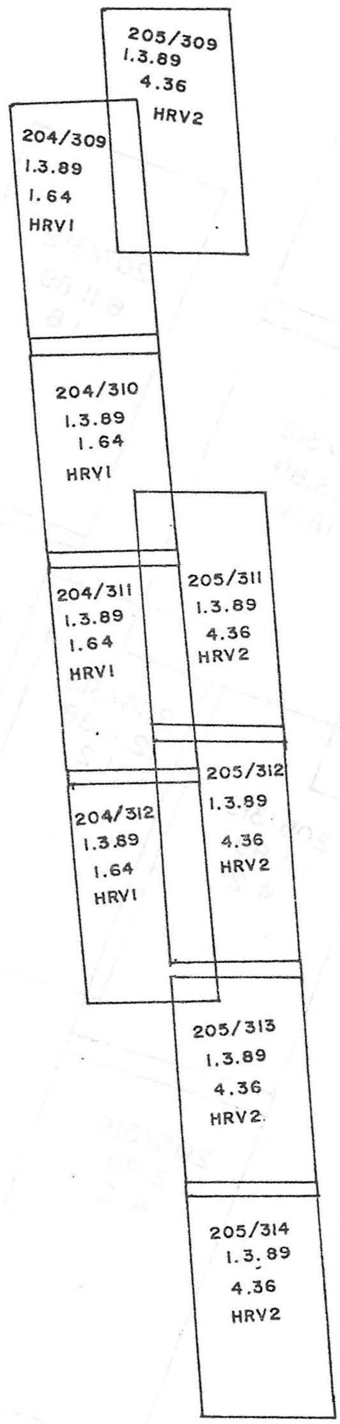

Fig 3.

KALYAN-PUNE-AHMADNAGAR

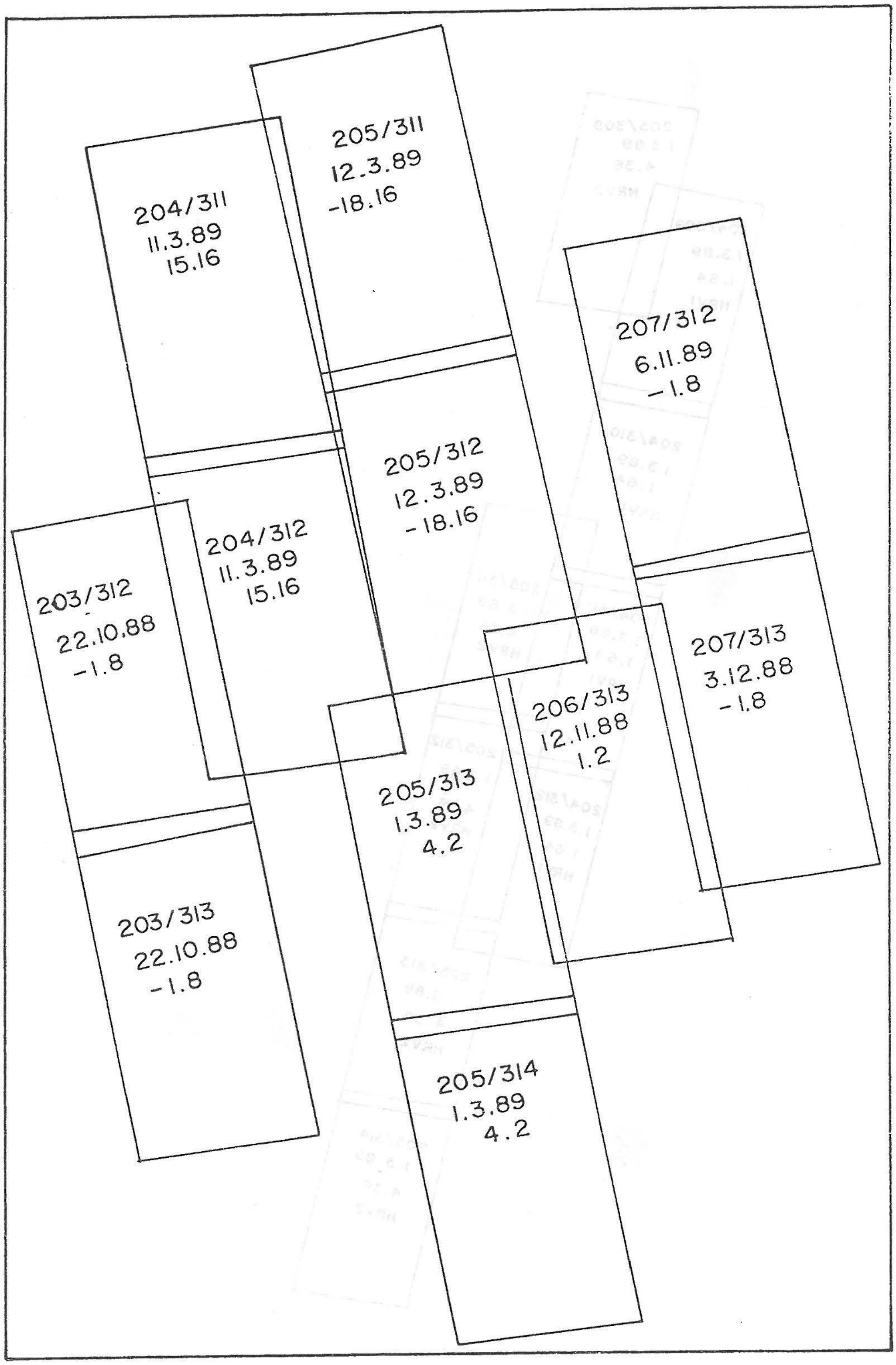

Fig 4.