PRECISION CORRECTION OF AWiFS TEMPORAL IMAGES FOR GEO-DATABASE CREATION

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ABSTRACT:

Spatial accounting and monitoring of land use and land cover (LULC) systems have become essential for the sustainable development of any country. In order to monitor these LULC systems a multi-temporal study is required at regular intervals. Indian Remote Sensing Satellite RESOURCESAT-1 (IRS-P6) has a unique sensor called AWiFS having medium resolution and wide ground swath and is designed to have around 80% overlap across adjacent paths. Hence this is one of the best-suited sensors for medium scale LULC temporal studies. Standard corrections cannot account for the errors caused due to its swath and terrain relief distortions. For getting the accurate registration with respect to temporal layers or maps an ortho-rectification procedure can be adopted. The Rigorous Sensor Model or the Rational Functional Model (RFM) can be used to ortho rectify such images. In relatively flat areas ortho-rectification is not necessary, but in mountainous terrains ortho rectification is essential.
Since the AWiFS camera has differing focal lengths between bands, performing ortho rectification using Rigorous Sensor model on these scenes demands more computations. Alternately a projective transformation approach based on RFM can correct the effects of the temporal data acquired through overlapping paths. The projective transformation simulates the sensor orientation while considering the terrain relief without looking for sensor information. Since this approach considers DEM, effects of terrain undulations can be rectified with high precision. This is a better tool for creating the spatio temporal database for carrying out the LULC natural resource studies. The accuracy of DEM and its corresponding ortho rectified data sets play a major role in the accuracy of the temporal registration. This methodology is presented in this paper, along with few case studies by considering the temporal AWiFS data sets over Indian regions.

1.INTRODUCTION

Accurate and timely spatial data is a cornerstone to a variety of applications. AWiFS is a unique camera having the capability to image a wide ground swath in medium resolution with tremendous potential for medium scale Land Use and Land Cover (LULC) studies. Even though the camera is nadir looking, because of relatively low focal length, the images need to be corrected for various scene and sensor induced effects including terrain relief, attitude and panoramic anomalies. The corrections can be carried out in several ways employing models such as (Murali Mohan,2005):

Physical Sensor Model.
Generic Sensor Model (RFM).
TIN based rectification for hills.
$1^{st}/2^{nd}$ degree polynomial model.

The generation of geometrically accurate information and the production of ortho- images in hilly areas are commonly carried out using a rigorous (physical) sensor model, sensor calibration information and GCPs. Although this model has become common practice, it is still difficult to meet this set of pre-requirements in many cases due to unavailable or missing information. Hence, this source of information is still beyond the reach of many potential user sectors. Unlike the rigorous sensor model, the Rational Function Model (RFM) provides a unified framework for the extraction of 2D or 3D information. The RFM derives sensor orientation and does not require any additional sensor information, thus providing an alternative to solving any image rectification.

Generalized sensor models, such as the usage of the Rational Function sensor Model (RFM) have alleviated the requirement to obtain a physical sensor model, and with it, the requirement for a comprehensive understanding of the physical model parameters. Consequently, the use of the RFM for photogrammetric mapping is becoming a new standard in high-resolution satellite imagery that has been already implemented in various high-resolution sensors, such as, IKONOS and Quick Bird and recently in Cartosat-1. There is tremendous work in this field being reported (Fraser and Hanley, 2003), (Ian and Tao 2002).

Exploiting the merits of the RFM is to provide an open approach in the area of photogrammetric utilization of the commercial high-resolution satellite images. The purpose of this paper is to explore how the RFM could be further utilized for ortho-rectification of AWiFS multispectral images. The application of RFM to AWiFS rectification appeared to be a prudent choice that the camera has differing focal lengths between SWIR band and the remaining bands. The following section describes AWiFS sensor.

2. THE AWiFS SENSOR

The AWiFS camera operates in four spectral bands. In order to cover the Wide field imaging with minimum geometric distortion, the AWiFS camera is realized using two separate electro-optic modules, which are tilted by 11.94° with respect to nadir. The specified area is viewed at different angles in different quadrants as well as in different paths. Each module covers a swath of 370 Km providing a combined swath of 740 Km with a side lap between them. This tilt of the sensor and the relief of the terrain cause displacement and hence an original un-rectified satellite image does not show features in their nadir view locations, as shown in Fig.1. The AWiFS camera has a spatial resolution of 56m and a radiometric resolution of 10 bits. Around 80 quadrants will cover the entire India.

LULC mapping and monitoring needs precise temporal registration of satellite data. Temporal data sets are used for classification. AWiFS data need to be acquired through the multiple paths to obtain the cloud free image. At the pre-processing level geometric correction, atmospheric correction and radiometric correction are applied. These corrections are not sufficient due to the feature displacements while imaging the same area from multiple paths.

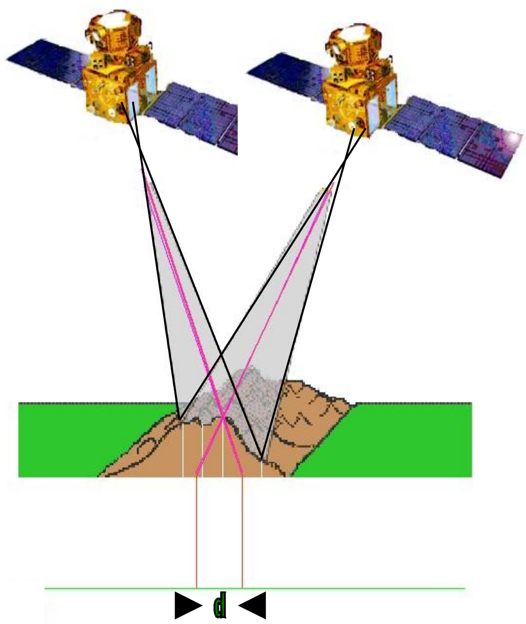

Figure 1: Feature displacement in multi-path acquisition.

3.GEO-RECTIFICATION

To meet the LULC temporal classification studies, the data needs to be geo-rectified with high location accuracy. The Geo-rectification involves the precision geometric correction of AWiFS quadrant scenes with geometrically rectified precision data as reference. Displacements caused due to the multi-path acquisition and the relief of the terrain are to be precision corrected. It is essentially required in the case of hilly terrains. Polynomial model is not very efficient in correcting these displacements. TIN based model for hilly terrain is highly localized and hence not fully reliable. Ortho-rectification is the alternate solution available (Tao, 2001a) if the sensor model is available.

3.1 Physical sensor model The physical sensor model represents the physical imaging process. The parameters involved describe the sensor's position and orientation with respect to an object-space coordinate system. The physical models are rigorous, such as co-linearity equations, and are very suitable for adjustment by analytical triangulation and normally yield high modelling accuracy. In physical models, parameters are statistically uncorrelated as each parameter has a physical significance.

Physical sensor models are sensor dependent, i.e., different types of sensors need different models. It is to be noted that rigorous physical sensor models are not always available. Without knowing its imaging parameters such as orbit parameters, sensor platform ephemeris data, relief displacement, earth curvature, atmospheric refraction, lens distortion etc., it would be highly involved to develop a rigorous physical sensor model.

3.2 Generalized sensor model Development of generalized sensor models, independent of sensor platforms and sensors becomes attractive due to the above reasons. In a generalized sensor model, the transformation between object and image space is represented as some general function without modelling the physical imaging process. The function can be of several different forms, such as polynomials or rational functions. In general, generalized sensor models do not require knowledge of the sensor geometry, thus they can be adapted to different sensor types.

The key to the use of generalized sensor model is that it must fit the physical sensor model well. Normally, the unknown coefficients in the generalized sensor model are solved using a 3D object grid and the corresponding image grid. Fitting the model to the object grid and corresponding image grid solves the parameters.

There are three generalized sensor models that have been used: the grid interpolation model, the RFM and the universal real-time model. In the grid interpolation model, a 3D grid in ground space is generated and the image coordinates for each grid point are computed using a physical sensor model. To find the image coordinates corresponding to specified ground coordinates, the surrounding grid points are found. Trilinear interpolation is then used between these eight points. The grid interpolation model does not produce adequate accuracy. The RFM uses ratios of polynomials to establish the relationship between the image coordinates and the object coordinates. The universal real time model is an extension to the RFM. It employs interpolation of high order correction functions. Use of RFM to approximate the physical sensor models has been in practice due to its unique characteristics of sensor independence and real time calculation.

4. RFM

4.1 Characteristics Mathematically, the disadvantage of using polynomials for approximation is their tendency for oscillation. This often causes error bounds in polynomial approximation to significantly exceed the average approximation error. The RFM has better interpolation properties. It is typically smoother and can spread the approximation error more evenly between exact fit points. The

RFM has the added advantage of permitting efficient approximation of functions that have infinite discontinuities near, but outside the interval of fitting, while a polynomial is unacceptable in this situation.

The RFM is independent of sensors and platforms. It also has coordinate system flexibility. It can accommodate object coordinates in any system such as geocentric, geographic, or any map projection coordinate system. RFM resembles projective equations very well. With adequate control information, the RFM can achieve a very high fitting accuracy. This is the primary reason why RFM has been used as a generalized sensor model.

The choice of a sensor model depends primarily on the performance and accuracy required, and the camera and control information available. In the case of AWiFS sensor, a rigorous physical sensor model is not available presently, to the user. In addition to this SWIR band focal length differs with the remaining bands. In the absence of a physical sensor model, RFM gives the better performance. Hence, projective transform, which is based on RFM, is used to correct AWiFS images to achieve accurate temporal registration, as this model does not depend on sensor position and orientation information.

4.2 Basic Relations The RFM relates object point coordinates (X, Y, Z) to image pixel coordinates (r, c) or vice versa in the form of rational functions that are ratios of polynomials. The RFM is essentially a generic form of the rigorous collinearity equations and the generalized sensor models including the 2-D and 3-D polynomial models, the projective transformation models and the (extended) direct linear transformation model. In order to minimize the introduction of errors during computations and improve the numerical stability of equations, the two image coordinates and three ground coordinates are each offset and scaled to fit the range from -1.0 to 1.0. For the ground to image transformation, the defined ratios of polynomials have the following form for each image section:

$$r_n = \frac{p_1(X_n, Y_n, Z_n)}{p_2(X_n, Y_n, Z_n)}$$

$$c_n = \frac{p_3(X_n, Y_n, Z_n)}{p_4(X_n, Y_n, Z_n)} \qquad (1)$$

where r_n = normalized row index of pixels in image
c_n = normalized column index of pixels in image
X_n, Y_n, Z_n= normalized coordinate values of object points in ground space.
p_1, p_2, p_3, p_4 = polynomials

The normalization of the coordinates is computed using the following equations:

$$r_n = \frac{r - r_0}{r_s}$$

$$c_n = \frac{c - c_0}{c_s} \qquad (2a)$$

$$X_n = \frac{X - X_0}{X_s}$$

$$Y_n = \frac{Y - Y_0}{Y_s} \qquad (2b)$$

$$Z_n = \frac{Z - Z_0}{Z_s}$$

where r_o ,c_o = offset values for the two image coordinates
r_s ,c_s = scale values for the two image coordinates
X_o, Y_o ,Z_o = offset values for the three ground co-ordinates
X_s, Y_s ,Z_s = scale values for the three ground co-ordinates

The maximum power of each ground coordinate is typically limited to 3; and the total power of all ground coordinates is also limited to 3. In such a case, each polynomial is of 20 term cubic form i.e.,

$$\begin{aligned} p &= \sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} a_{ijk} X^i Y^j Z^k \\ &= a_0 + a_1\ Z + a_2\ Y + a_3\ Z + a_4\ ZY \\ &+ a_5\ ZX + a_6\ YX + a_7\ Z^2 + + a_8\ Y^2 + a_9\ X^2 \\ &+ a_{10}\ ZYX + a_{11}\ Z^2\ Y + a_{12}\ Z^2\ X + a_{13}\ Y^2\ Z \\ &+ a_{14}\ Y^2\ X + a_{15}\ ZX^2 + a_{16}\ YX^2 + a_{17}\ Z^3 \\ &+ a_{18}\ Y^3 + a_{19}\ X^3 \end{aligned} \qquad (3)$$

where a_{ijk} = polynomial coefficients called Rational Function Coefficient (RFC)

In general, distortions caused by optical projection can be corrected by ratios of first order terms, and corrections to earth curvature, atmospheric refraction lens distortion etc., can be well approximated by the second order terms. Some other unknown distortions with high order components, such as camera vibration can be modelled with the third order terms.

4.3 Solution of the RFC The unknown RFCs can be solved by least-square adjustment. The normal equation is given by Eq.4 (Tao and Hu,2001a).

$$T^T WTI - T^T TWG = 0 \qquad (4)$$

where I = vector of RFCs
T = design matrix of the linearized observation equations (Eq. 1)
W=weight matrix for image pixel coordinate G

The covariance matrix associated with I is given by (Hu and Tao, 2002)

$$P = \left(T^T W T\right)^{-1} + R \quad (5)$$

To tackle the ill-conditioning problem during the adjustment, the Tikhonov regularization technique was suggested to turn the normal equation into a regularized equation. The RFCs can be solved iteratively as follows:

$$I_k = I_{k-1} + \left(T\,TW_{k-1}T + h^2 E\right)^{-1} T^T W_{k-1} w_{k-1}$$

for k=1,2,….

with $I_0 = 0,\ W_0 = W\left(I_0\right) = E$ (6)

where h = regularization parameter;

k = iteration number

$W_k = W(I_k)$ is the weight matrix

$w_k = G\text{-}TI_k$ is the misclosures at GCPs.

4.4 Terrain dependent approach The RFCs of the RFM can be solved for with or without knowing the physical sensor models. The RFCs can be solved by terrain independent scenario using known physical sensor models or by terrain dependent scenario without using physical sensor models. The achievable accuracy in terrain independent scenario is virtually equivalent to the accuracy of the original physical sensor model. Otherwise, the solution will be highly dependent on the input control points and the terrain surface (Hu,,Tao and Arie, 2004b).

For the terrain-dependent scenario, with no physical sensor models at hand, the 3D object grid cannot be established. The RFM tries to approximate the complicated imaging geometry across the image scene using its plentiful polynomial terms and the solution is highly dependent on the actual terrain relief, the number of GCPs and their distribution across the scene. The GCPs and checkpoints have to be collected in a conventional manner. The iterative least square with regularization is then used to solve for the RFCs. In this context, the RFM behaves as a rubber sheeting model, and the over-parameterization may cause the design matrix of the normal equation to become almost rank deficient because of the complex correlation among RFCs. The regularization technique improves the condition of the design matrix, and thus avoids numerical instability in the least squares adjustment.

Studies show that accuracy is high, provided that a large number of GCPs are collected across the whole scene. GCPs should be well distributed to cover all the contour intervals and good spatial distribution also should be ensured. Nevertheless, the terrain dependent approach may not provide a sufficiently accurate and robust solution if the above requirements for control information is not satisfied. Image rectification of remote sensing imagery is done using terrain dependent approach when the rigorous physical sensor model is not available, and when the accuracy requirement is not very stringent. Hence, for AWiFS temporal registration, this methodology is evaluated.

5. TEST RESULTS

Ortho-corrected image in LCC projection with WGS 84 datum is used as reference. GCPs are collected interactively from the reference image along with the DEM. The GCPs are evenly distributed covering the different contour intervals. DEM with 90m contour intervals is used. Least square solution with regularization is used to solve the RFCs. Rational polynomial with different denominators are used in correcting AWiFS images since it gives the best results.

Few AWiFS quadrants of Indian region were generated using projective transform method. These scenes were selected in such a way that they cover the different types of terrains like hilly, partial hilly and plain regions in the Western Ghats and Jammu & Kashmir. These products were evaluated for their temporal registration accuracy. The shift in x and y-direction at particular lat/longs are shown in Tables 1 and 2.

IRS AWiFS:100/50 C - 24Aug2005				
	AREA : Uttaranchal			
Sl.	Longitude	Latitude	Diff-horiz(m)	Diff-vert(m)
1	79 15 02.83	29 33 07.93	18.69	22.66
2	79 27 57.61	29 30 57.61	32.05	37.38
3	79 38 37.74	29 39 55.64	23.11	90.66
4	78 04 10.58	29 41 24.27	60.36	38.17
5	78 06 13.41	29 38 29.43	52.41	52.94
6	78 09 00.61	29 34 42.61	37.43	30.87
7	78 05 40.84	29 27 13.74	44.92	40.32
8	78 21 38.36	29 18 58.16	52.41	52.41
9	78 34 00.69	29 19 19.84	44.92	45.54
10	78 33 23.21	29 14 53.86	60.36	44.92

Table 1: Location differences between reference & rectified.

IRS AWiFS : 93/44 C - 13aug2005				
	Area : Jammu & Kashmir			
Sl.	Longitude	Latitude	Diff-horz(m)	Diff-vert(m)
1	74 37 33.70	35 44 35.15	66.55	38.81
2	74 37 23.19	35 39 52.84	85.23	47.06
3	74 16 20.07	35 26 16.11	37.65	47.06
4	73 54 49.99	35 28 49.50	56.47	28.24
5	73 47 28.19	35 31 08.52	37.65	37.65
6	73 30 39.46	35 31 59.44	47.06	47.99
7	72 36 47.94	35 19 40.04	57.25	75.29
8	72 32 54.90	35 12 29.50	57.25	112.4
9	72 28 56.81	35 04 29.01	28.24	65.88
10	72 25 40.83	34 53 32.36	65.88	56.47

Table 2: Location differences between reference & rectified

It was observed that the registration accuracy achieved using the projective transform method was less than two pixels in the highly hilly terrains. This method has a localized effect, and hence GCPs has to be well distributed. It was also observed that DEM accuracy has a very high impact on the result of the temporal registration. Case studies were taken up to evaluate the impact of DEM on the registration accuracy. Images of North-East and South-West regions of India were studied. DEM from two different sources were used in the study – 90m DEM (DEM1) (Murthy, 2004) and 90m SRTM-DEM (DEM2). DEM1 has a high planimetric accuracy of less than 1 pixel whereas DEM2 is less accurate with respect to the ortho-rectified reference used.

A detailed study was carried out over the Kudremukh-India region using accurate DEM and SRTM-DEM. AWiFS data was rectified through Projective Transform using DEM1 & DEM2 keeping in reference individually and results were compared with ortho-rectified reference. AWiFS day 2 was rectified through projective transform and compared with AWiFS day 1 projective transform corrected as reference.

Orthorectified (ref. DEM1) Vs AWiFS				
Sl	Latitude	Longitude	diff-hor (pix)	diff-vert (pix)
1	13 10 25.0	75 14 35.2	0.2	0.6
2	13 06 10.4	75 11 47.1	0.4	1.1
3	13 12 26.5	75 00 46.1	0.1	0.4
4	13 05 30.5	75 09 35.6	0.7	1.0
5	13 13 25.9	75 1 58.6	0.1	1.0
6	13 10 13.3	75 10 55.2	0.6	0.1
7	13 20 48.0	75 2 46.1	0.1	0.6
8	13 20 56.8	75 10 32.8	0.6	0.3
9	13 15 09.2	75 7 7.1	0.1	0.4
10	13 20 04.4	75 5 59.9	1.0	0.6

Table 3: Location differences between reference - DEM1 & AWiFS.

Orthorectified (ref. DEM2) Vs AWiFS				
Sl	Latitude	Longitude	diff-hor (pix)	diff-vert (pix)
1	13 12 44.27	75 14 08.68	1.4	0.4
2	13 10 45.27	75 14 29.54	0.2	2.0
3	13 15 19.17	75 02 48.67	0.9	0.7
4	13 16 13.11	75 05 13.74	0.9	0.9
5	13 10 44.54	75 14 58.29	0.7	0.8
6	13 13 25.41	75 18 47.90	1.3	1.0
7	13 06 58.03	75 17 31.29	0.4	0.4
8	13 01 42.15	75 01 44.01	1.2	1.4
9	13 20 10.70	75 10 12.74	1.8	0.8
10	13 21 53.52	75 40 30.30	3.7	3.8

Table 4: Location differences between reference – DEM2 &AWiFS.

AWiFS DEM1 Vs AWiFS DEM2				
Sl	Latitude	Longitude	diff-hor (pix)	diff-vert (pix)
1	13 14 16.2	75 04 28.9	1.4	0.5
2	13 19 22.4	75 04 02.7	0.5	0.5
3	13 20 37.3	75 21 26.6	0.4	0.7
4	13 28 38.1	75 28 11.1	0.5	0.6
5	13 20 37.1	75 04 02.6	0.5	0.5
6	13 15 16.3	75 02 48.4	0.6	0.4
7	13 24 54.1	75 05 11.2	0.5	0.6
8	13 10 25.1	75 14 35.4	0.6	0.4
9	13 07 55.6	75 12 41.9	0.5	0.4
10	13 16 18.2	75 29 39.7	0.5	0.7

Table 5: Location differences using DEM1 & DEM2.

AWiFS(D1) Vs AWIFS(D2)-(DEM1 as reference)				
Sl.	Latitude	Longitude	diff-hor (pix)	diff-vert (pix)
1	13 29 28.1	75 01 7.8	0.2	0.2
2	13 29 22.6	75 02 42.7	0.3	0.1
3	13 29 8.2	75 04 43.7	0.2	0.0
4	13 28 1.0	75 03 40.5	0.2	0.1
5	13 24 20.2	75 04 45.8	0.3	0.1
6	13 20 37.9	75 06 00	0.2	0.0
7	13 18 30.4	75 07 44.7	0.2	0.1
8	13 15 10.0	75 09 71.5	0.2	0.1
9	13 03 37.6	75 12 59.3	0.4	0.2
10	13 00 30.0	75 11 28.2	0.2	0.3

Table 6: Location differences between temporal data sets.

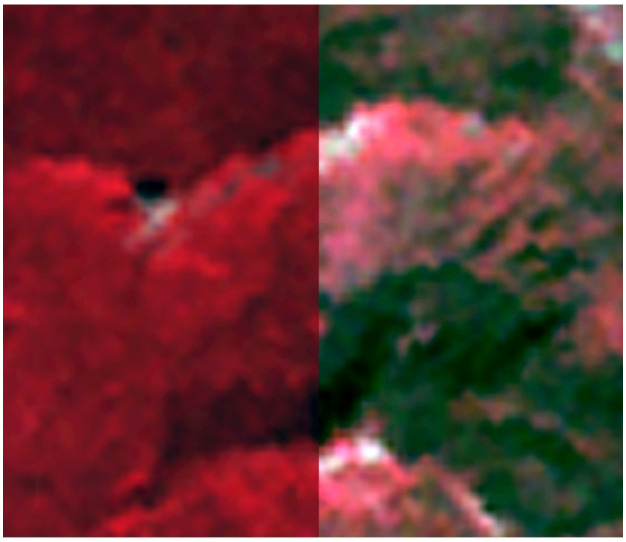

Fig 2: Indian region AWiFS temporal registration.

Temporal registration across two different AWiFS data sets was also carried out. Results are shown in Tables 3,4,5 and 6. The tables show how DEM accuracy affects the overall accuracy of the scene. Figure 2 shows the temporal registration of AWiFS.

It was observed that DEM with higher accuracy gives better results compared to the one with lower planimetric accuracy.

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6. CONCLUSIONS

In this paper, a novel method for precision correction of AWiFS images for geo-database creation is discussed. For the AWiFS sensor, the scenes captured from two different positions cannot be registered accurately using polynomial model, especially in the hilly terrain. Ortho-rectification is the alternate solution available. In the absence of physical sensor model, RFM is the better method available to accurately register the AWiFS images since it can correct the displacement of features in the image due to terrain relief. However, this method is highly dependent on the number of GCPs, their distribution and the accuracy of DEM used. To understand the effect of DEM accuracy on the registered scene, study was carried out and observed that the DEM with the higher accuracy can achieve the better registration. Hence, availability of accurate DEM is very essential in obtaining high temporal registration. It is recommended that an automatic GCP generation can be used to produce large number of GCPs to improve the registration accuracy.

A geo-database can be created for such temporal datasets of AWiFS. Further, these datasets can be used in classification for LULC mapping and other related studies. Temporal registration accuracy should be high to obtain reliable results. RFM based projective transform can be used to register such images temporally, along with accurate reference 3D control points.

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SRTM DEM
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