An Approach to Improve Multistrip Data Product Accuracy Through Overlap Analysis

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Keywords: image data product, step and stare imaging, multistrip imaging, geometric accuracy, overlap analysis

Abstract

The image data of a high resolution satellite operating in step and stare mode, having four strips with 400 to 600 pixels overlap between the adjacent strips was used to improve the product accuracy through overlap analysis. The information of overlap between adjacent strips in the form of relative control points (RCP) was used to update the attitude parameters (roll & pitch) for specific time duration. The evaluation of the updated attitude parameters has been made using common GCPs of about 10 m accuracy available in adjacent strips using Ground to Image, Image to Ground and Image to Image transformations. The mean and standard deviation of errors were computed for all these transformations using original and updated attitude. The comparison of these results show, mean and standard deviation reduced significantly in case of updated attitude parameters, which is a clear indication of decrease in internal distortion due to updated roll and pitch values.

Overview

1. Introduction

The precise imaging geometry and the capability of the imaging model are the prime aspects for achieving better geometric (location) accuracy as well as product quality for any satellite data product. In case of high resolution satellites these quantities become very crucial, which are highly dependent on the attitude parameters of the satellite. The geometric quality of product can be improved by re-establishment of imaging geometry from image data or by updating the attitude parameters using a few ground control points. The inflight calibration (Srivastava and Alurkar, 1997) is also one of the exercises that can be done to improve the product accuracy in case of remote sensing satellites having multistrip imaging. Such exercises are also reported for SPOT (Boissin and Gardelle, 1986) and MOMS (Kornus and Lehner, 1996). In this paper a method to improve the product accuracy using the overlap information has been described.

2. Methodology

A formal approach has been used to update the attitude parameters using overlap information with the help of relative control points (RCP) identified in adjacent strips. In this method an image to image (I2I) transformation model to swap between the strips has been used. This is a function of image to ground (I2G) and ground to image (G2I) models are which relate a given image point to its corresponding ground point. These two transformations are used to relate an image point of one CCD to the corresponding image point of the adjacent CCD, through ground.

2.1 Image to Ground Model (I2G): The fundamental relationship between the image point, object and perspective centre of the sensor can be given as the basic collinearity condition

$$\begin{bmatrix} f \\ -x \\ -y \end{bmatrix} = kM \begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix} \tag{1}$$

where, M is a transformation matrix, which is a function of orientation parameters (orbit, attitude, look angle), (X_A, Y_A, Z_A) and (X_S, Y_S, Z_S) are ground coordinate and perspective centre coordinate at the time of imaging, (f, -x, -y) is the image coordinate of the same ground point and k is the scale factor.

Therefore inverse collinearity equation can be written as

$$\begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix} = k' M^T \begin{bmatrix} f \\ -x \\ -y \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix} = k' \begin{bmatrix} L \\ M \\ N \end{bmatrix} \tag{3}$$

where, (L,M,N) denotes the expression $M^T(f, -x, -y)$ and k' is the reciprocal of k. Then,

$$X_A = X_S + k'.L$$
$$Y_A = Y_S + k'.M \qquad (4)$$
$$Z_A = Z_S + k'.N$$

The ground point (X_A, Y_A, Z_A) must lie on the earth ellipsoid and therefore satisfy the equation

$$\frac{X_A{}^2}{a^2} + \frac{Y_A{}^2}{a^2} + \frac{Z_A{}^2}{b^2} = 1 \qquad (5)$$

where, a and b are the semi major and minor axes of the earth's ellipsoid. From equations 4 and 5, a quadratic equation in k' can be written as

$$A.k'^2 + B.k' + C = 1 \qquad (6)$$

By solving the above equation, k' can be determined. Therefore (X_A, Y_A, Z_A) can be determined by substituting k' in equation 4.

2.2 Ground to Image Model (G2I): The collinearity equation can be written as follows:

$$(x.M_1+f.M_2).(X_A-X_S)=0 \qquad (7)$$

$$(y.M_3+f.M_2).(X_A-X_S)=0 \qquad (8)$$

where, M_1, M_2 and M_3 are the row vectors of matrix M.

In order to determine scanline number, time t at which the ground point (X_A, Y_A, Z_A) was imaged must be determined. Therefore the equations 7 and 8 must equate to zero at this time. Hence to determine the time t, these equations must be solved iteratively between scene start time t_1 and scene end time t_2. Once time t is found, the scan line can be computed as

$$Scanline = t/integration\_time$$

Now focal plane coordinate (x, y) can be found out from equations 7 and 8, as

$$x = -f\,\frac{M_2.(X_A - X_S)}{M_1.(X_A - X_S)} \quad y = -f\,\frac{M_2.(X_A - X_S)}{M_3.(X_A - X_S)} \qquad (9)$$

Therefore pixel value can be determined by using equation 9,

$$Pixel = (y/d) - start\_pixel\_bias$$

where, d is the detector size and start_pixel_bias is the distance of first pixel of a particular CCD from the optical centre.

2.3 Finding Relative Control Points (RCP) and Error Estimation: This approach primarily depends upon the relative control points in the overlap region of the strips. The RCPs with their scan, pixel coordinates have been identified in the two consecutive strips like 1 & 2, 2 & 3 and 3 & 4 (assuming a four CCD configuration, Figure 1) in the overlap region (e.g. (S1, P1), (S2, P2) for strip 1 and strip 2). The exact coordinate corresponding to a reference point in one CCD (reference is always left CCD) is found out using digital correlation/ image matching methods. These RCPs are found out for various sizes of strips like 4K, 8K, 16K and 32K, taking every 5th scan line.

Once the exact coordinates of the points in adjacent CCDs are available, this data has been given to image to ground model (for strip 1) as input which finds the latitude and longitude coordinates of the point (S1, P1). Then these latitude, longitude coordinates are passed to ground to image model, which estimates the corresponding scan and pixel (S2es, P2es) in strip 2. The error has been computed in this procedure as (S2es-S2, P2es-P2) where, (S2, P2) is the coordinate of the point in strip 2 corresponding to (S1, P1). This procedure can be repeated for all radiometrically corrected adjacent image strips in forward as well as in reverse directions like 1→ 2 & 2 → 1, 2 → 3 & 3 → 2, and 3 → 4 & 4 → 3.

2.4 Updating Attitude from Overlap Information: As stated above, the estimated scan, pixel difference can be calculated using I2I (I2G and G2I) between two adjacent strips. This scan and pixel difference (S2es-S2, P2es-P2) is nothing but the uncertainty in attitude at that time for the corresponding RCP time. This difference is converted into the pitch and roll errors (Δpitch, Δroll) respectively using payload geometry. From the original attitude, a new attitude is formed at RCP times. Delta roll & delta pitch at a particular RCP are added to the original values of roll and pitch respectively. This process is repeated until the residual delta roll and delta pitch become very small ($< 10^{-5}$) for the corresponding RCP time.

3. Evaluation of Updated Attitude

For evaluating the updated attitude, a GCP based approach has been adopted. The IRS-IC/ID image base map of about 10 m accuracy has been identified as a reference for this purpose. Ten GCPs are collected in the overlap region of two adjacent strips, which is given in the Table 1. The strips at junction of interest can be called as left and right strip.

The evaluation of updated attitude has been done for all transformations viz. I2G, G2I and I2I. The evaluation for image to image transformation (I2I) has been done in both directions between left and right strips (left → right & right →left). The summary of the results for each transformation has been given in Table 2. Actual GCP coordinates are used as input to G2I model and estimated image point (scan, pixel) is calculated for both the strips. Similarly, the actual image point of left strip and right strip are used as input to I2G to estimate the ground coordinate (latitude, longitude). The errors in latitude and longitude estimation have been computed for all ten points. Also, the actual image point of left strip has been used for I2I model to estimate the errors in scan and pixel in forward (left to right) direction. Similarly, image point of right strip is used for backward (right to left) direction.

Table 1: Image coordinates of GCPs in the overlap region of left & right strips

Overlap GCP	Left Strip		Right Strip	
No.	Scan	Pixel	Scan	Pixel
1	1459	3718	148	170
2	3122	4090	1827	537
3	4792	3673	3514	120
4	5168	3696	3893	143
5	5997	3708	4730	153
6	6476	3898	5211	341
7	6834	3811	5573	255
8	7549	3784	6293	227
9	9255	3618	8011	61
10	9948	3709	8708	149

Location accuracy results on these GCP points, with original attitude and with updated attitude between the strips are compared.

4. Results and Discussions

Using the estimation errors, the maximum, minimum, mean and standard deviation have been computed for all transformations, G2I, I2G and I2I, and are given in Tables 2, 3, and 4 respectively. Also, these errors have been calculated by taking one GCP as a reference (2^{nd}, 6^{th} and 10^{th}) as individual bias, which is subtracted, from all points. This process is also repeated for the average error by taking all GCPs. In Tables 2 and 3, the column entitled "Scan/ Lat.Err.(-avg)" and "Pix/ Long.Err.(-avg)" are tabulated after the mean bias (average of errors) is subtracted from all these points. Similarly the columns with flags -2nd, -6th and –10th, comprise of the errors after subtracting the 2^{nd}, 6^{th}, and 10^{th} GCP error as a bias from all points. Table 4 presents the errors in I2I in forward and reverse directions.

A close look at the results show that without updated or with updated attitude, the location accuracy is about 1.9 km along track and 1.7 km across track for both strips, which is the system level accuracy. This shows that the updated attitude with overlap analysis is not improving the bias component significantly. The improvement is of the order of 35 and 30 m along track for left strip and right strip respectively. While across track it is 50 m for both strips.

Table 2 presents G2I estimation error variation in left and right strips. With original attitude the scan and pixel errors vary from -1908.6 to –1978.6 m and 1622.9 to 1714.3 m respectively, while with updated attitude, the variation becomes –1908.6 to –1943.2 m and 1674.8 to 1741.8 m. Similarly for the right strip, the scan and pixel errors vary from –1916.7 to –2008.0 m and 1633.8 to 1733.4 m respectively with original attitude and after updating, the range becomes –1916.7 to –1973.6 m and 1692.7 to 1735.6 m.

Table 3 shows I2G estimation error variations in latitude and longitude direction for left and right strips. For left strip, the latitude and longitude errors vary from -0.0179 to -0.0183 degrees and -0.0177 to -0.0192 degrees respectively with original attitude, while after updating these variations become -0.0177 to -0.0179 degrees and -0.0191 to -0.0195 degrees. Similarly, for right strip the latitude and longitude errors vary from -0.0178 to -0.0184 degrees and -0.0179 to -0.0195 degrees respectively with original attitude and with updated attitude, latitude and longitude errors vary from -0.0178 to -0.0181 degrees and from -0.0191 to -0.0195 degrees respectively.

Table 4 presents the I2I (from left to right strip) estimation errors. Scan and pixel errors vary from 7.5 to –30.8 m and 24.1 to 14.1 m respectively with original attitude. With updated attitude, the variation becomes –12.3 to –22.0 m and –7.0 to 1.8 m.

The standard deviation is reduced to 10.5 m from 20.9 m in case of G2I estimations in along track and reduced to 17.8 m from 26.1 m in across track for left strip. For right strip it has become 15.8 m from 28.5 m, 14.7 m from 28.7m in both along and across track directions. On the other side, in I2G estimation, the standard deviation reduced to half, 1.38E-4 to 7.76E-5 and 1.62E-4 to 8.36E-5 for left and right strips respectively in along track direction. While, it becomes ¼th (4.31E-4 to 1.12E-4 and 4.62E-4 to 1.10E-4 all in degrees for left and right strips) in across track direction. The standard deviation in case of I2I estimation along track, reduced from 11.65 m to 2.65 m in forward (left → right strip) and become 11.66 m to 3.94 m in reverse direction (right → left strip) estimation. It remains almost constant in across track direction for left à right and right→left in I2I estimation.

The decrease in the range of variation and standard deviation can be attributed to decrease in internal distortion due to updating the attitude parameters (roll and pitch) using overlap information. Therefore, by updating the attitude parameters through overlap information, the internal distortion can be reduced need to significantly. However more cases need to be analyzed including full pass, which may result in significant removal of internal distortion of scenes.

5. Acknowledgements

The authors wish to express their special gratitude to Dr. K. L. Majumder, Group Director, SIPG/SIIPA for his constant encouragement and support to this work. The authors are also indebted to Shri. T. P. Srinivasan, for guiding at various stages of this work. The constant help from Shri. Devakanth Naidu and Shri. Sanjay Singh, in the form of fruitful discussions and programming support are highly acknowledged.

6. References

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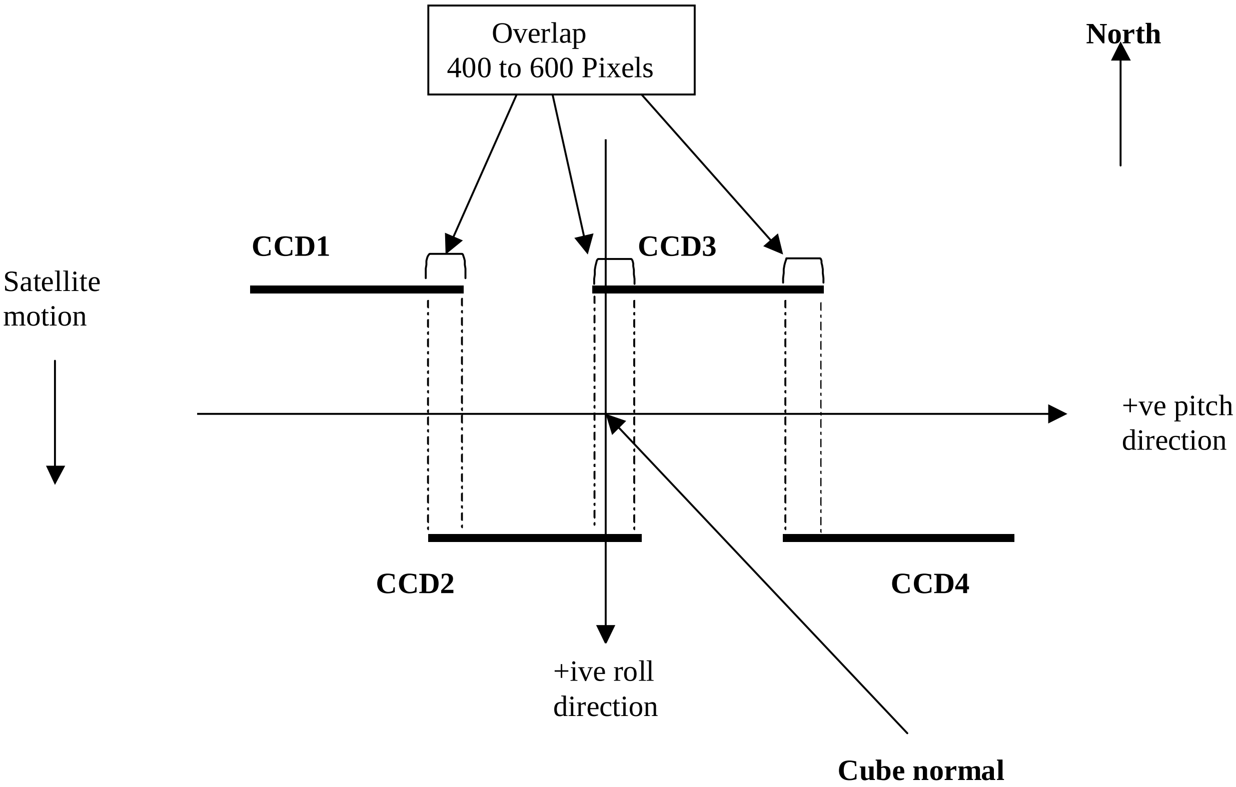

Figure 1- CCD Arrangement in Camera

Table 2: Ground to image estimation errors for left and right strips
Error in Scan and Pixel (m)

Left Strip

Original Attitude

	Scan Err.	Pix Err.	Scan. Err (avg)	Pix Err. (avg)	Scan Err. (2nd)	Pix Err. (2nd)	Scan Err. (6th)	Pix Err. (6th)	Scan Err. (10th)	Pix Err. (10th)
max	-1908.6	1714.3	53.1	59.3	34.6	39.5	62.6	69.6	62.6	91.4
min	-1978.7	1622.9	-17.0	-32.1	-35.5	-51.9	-7.5	-21.8	-7.4	0.0
mean	-1961.7	1655.0	0.0	0.0	-18.5	-19.8	9.6	10.3	9.6	32.1
stdev	20.9	26.1	20.9	26.1	20.9	26.1	20.9	26.1	20.9	26.1

Updated Attitude

max	-1908.6	1741.8	19.1	28.0	34.6	67.0	18.5	32.8	17.8	0.0
min	-1943.2	1674.8	-15.5	-38.9	0.0	0.0	-16.0	-34.2	-16.8	-67.0
mean	-1927.7	1713.8	0.0	0.0	15.5	38.9	-0.5	4.8	-1.3	-28.0
stdev	10.5	17.8	10.5	17.8	10.5	17.8	10.5	17.8	10.5	17.8

Right Strip

Original Attitude

	Scan Err.	Pix Err.	Scan. Err (avg)	Pix Err. (avg)	Scan Err. (2nd)	Pix Err. (2nd)	Scan Err. (6th)	Pix Err. (6th)	Scan Err. (10th)	Pix Err. (10th)
max	-1916.7	1733.4	69.1	64.0	40.9	40.7	78.9	74.2	91.3	99.6
min	-2008.0	1633.8	-22.3	-35.6	-50.4	-58.9	-12.5	-25.4	0.0	0.0
mean	-1985.7	1669.4	0.0	0.0	-28.1	-23.3	9.8	10.2	22.3	35.6
stdev	28.5	28.7	28.5	28.7	28.5	28.7	28.5	28.7	28.5	28.7

Updated Attitude

max	-1916.7	1735.6	40.1	23.0	40.9	42.9	45.0	31.3	38.9	0.0
min	-1973.6	1692.7	-16.8	-19.9	-16.0	0.0	-11.9	-11.6	-18.0	-42.9
mean	-1956.8	1712.6	0.0	0.0	0.8	19.9	4.9	8.3	-1.3	-23.0
stdev	15.8	14.7	15.8	14.7	15.8	14.7	15.8	14.7	15.8	14.7

Table 3: Image to ground estimation errors for left and right strip
Error in latitude and longitude (degrees)

Left Strip

Original Attitude

	Lat. Err.	Long. Err.	Lat. Err. (avg)	Long. Err (avg)	Lat. Err. (2nd)	Long. Err. (2nd)	Lat. Err. (6th)	Long. Err. (6th)	Lat. Err. (10th)	Long. Err. (10th)
Max	-1.79E-02	-1.77E-02	2.23E-04	5.76E-04	2.47E-04	9.82E-04	2.94E-04	4.47E-04	1.53E-05	4.00E-08
Min	-1.83E-02	-1.92E-02	-1.54E-04	-9.04E-04	-1.30E-04	-4.99E-04	-8.22E-05	-1.03E-03	-3.61E-04	-1.48E-03
Mean	-1.81E-02	-1.83E-02	1.80E-08	2.70E-08	2.39E-05	4.05E-04	7.16E-05	-1.29E-04	-2.07E-04	-5.76E-04
Stdev	1.38E-04	4.31E-04	1.38E-04	4.31E-04	1.38E-04	4.31E-04	1.38E-04	4.31E-04	1.38E-04	4.31E-04

Updated Attitude

Max	-1.77E-02	-1.91E-02	1.05E-04	1.28E-04	1.38E-04	1.24E-04	2.02E-05	1.61E-04	1.46E-04	4.90E-07
Min	-1.79E-02	-1.95E-02	-1.29E-04	-2.78E-04	-9.66E-05	-2.82E-04	-2.14E-04	-2.45E-04	-8.87E-05	-4.05E-04
Mean	-1.78E-02	-1.92E-02	-3.00E-09	-4.00E-09	3.26E-05	-4.00E-06	-8.51E-05	3.28E-05	4.05E-05	-1.28E-04
Stdev	7.76E-05	1.12E-04	7.76E-05	1.12E-04	7.76E-05	1.12E-04	7.76E-05	1.12E-04	7.76E-05	1.12E-04

Right Strip

Original Attitude

	Lat. Err.	Long. Err.	Lat. Err. (avg)	Long. Err (avg)	Lat. Err. (2nd)	Long. Err. (2nd)	Lat. Err. (6th)	Long. Err. (6th)	Lat. Err. (10th)	Long. Err. (10th)
Max	-1.78E-02	-1.79E-02	4.09E-04	6.13E-04	3.08E-04	1.06E-03	4.95E-04	4.86E-04	3.63E-04	1.00E-08
Min	-1.84E-02	-1.95E-02	-1.48E-04	-9.62E-04	-2.50E-04	-5.19E-04	-6.23E-05	-1.09E-03	-1.95E-04	-1.57E-03
Mean	-1.83E-02	-1.85E-02	3.40E-08	4.00E-09	-1.01E-04	4.43E-04	8.57E-05	-1.27E-04	-4.69E-05	-6.13E-04
Stdev	1.62E-04	4.62E-04	1.62E-04	4.62E-04	1.62E-04	4.62E-04	1.62E-04	4.62E-04	1.62E-04	4.62E-04

Updated Attitude

Max	-1.78E-02	-1.91E-02	1.10E-04	1.15E-04	1.36E-04	1.20E-04	2.39E-05	1.47E-04	1.38E-04	3.60E-07
Min	-1.81E-02	-1.95E-02	-1.55E-04	-2.75E-04	-1.29E-04	-2.70E-04	-2.41E-04	-2.43E-04	-1.27E-04	-3.90E-04
Mean	-1.79E-02	-1.92E-02	-1.00E-09	4.60E-08	2.56E-05	4.45E-06	-8.63E-05	3.18E-05	2.73E-05	-1.15E-04
Stdev	8.36E-05	1.10E-04	8.36E-05	1.10E-04	8.36E-05	1.10E-04	8.36E-05	1.10E-04	8.36E-05	1.10E-04

Table 4: Image to image estimation errors (left to right strip and right to left strip)
Error in Estimation in Scan and Pixel (m)

Left to Right Strip

Original Attitude

	Scan Err.	**Pix Err.**
Max	7.5	24.1
Min	-30.8	14.1
Mean	-12.9	18.8
Stdev	11.7	3.0

Updated Attitude

Max	-12.3	1.8
min	-22.0	-7.0
mean	-15.3	-0.1
stdev	2.7	2.8

Right to Left Strip

Original Attitude

	Scan Err.	**Pix Err.**
max	31.2	-14.2
min	-7.1	-24.4
mean	13.3	-19.0
stdev	11.7	3.1

Updated Attitude

max	26.3	10.8
min	13.0	-1.9
mean	16.4	0.8
stdev	3.9	4.1