Line Based Transformation Model (LBTM) for high-resolution satellite imagery rectification

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Abstract: Traditional photogrammetry and satellite image rectification technique have been developed based on control-points for many decades. These techniques are driven from linked points in image space and the corresponding points in the object space in rigorous colinearity or coplanarity conditions. Recently, digital imagery facilitates the opportunity to use features as well as points for images rectification. These implementations were mainly based on rigorous models that incorporated geometric constraints into the bundle adjustment and could not be applied to the new high-resolution satellite imagery (HRSI) due to the absence of sensor calibration and satellite orbit information.

This research is an attempt to establish a new Line Based Transformation Model (LBTM), which is based on linear features only or linear features with a number of ground control points instead of the traditional models that only use Ground Control Points (GCPs) for satellite imagery rectification. The new model does not require any further information about the sensor model or satellite ephemeris data. Synthetic as well as real data have been demonestrated to check the validity and fidelity of the new approach and the results showed that the LBTM can be used efficiently for rectifying HRSI.

Keywords: Remote Sensing, Geometry, Rectification, Georeferencing, Model, High-resolution.

1. Introduction

For several decades, the rigorous mathematical models for expressing the relationship between image space and object space are based on ground control points in perspective geometry. However, GCPs may not be available due to difficulties of locating features in ground and points identification. Recently, digital imagery has open up the opportunity to use features to facilitate the geometric correction process. There are several trials to replace the traditional treatment point-based mathematical models by linear-based one. However, most of these techniques are proposed to use linear features as constraints and still based on the same rigorous mathematical models, which needs all information for the sensor model.

Although the previous techniques could be applied to frame imagery and some linear array scanner sensors, some limitations can be recorded for applying such techniques to High Resolution Satellite imagery, which can be summarized in the followings: a) all the presented models are based on rigorous mathematical models derivation which are based on several parameters that are not available for the users; b) most of these models are valid for projective geometry representation which is not exactly the case for the satellite imagery; c) the models are quite complicated regarding the geometry of the linear array scanners and time dependency; d) numerical problems can be encountered because of the initial approximation.

Here we present a new generic model that can be used in high-resolution satellite imagery rectification and 3D geo-positioning determination. The new model considers various photogrammetric operations such as space resection for calculating the model coefficients and space intersection for determining the points location. In this work, most of the encountered problems using the linear features with the present generation of models have been overcome. The new model is very simple and can be applied to images from any linear array sensors when it is time independent, does not require any further information about sensor calibration and satellite orbit information, and does not require any initial approximation values. A comparative study has been presented to determine the effectiveness and limitation of the new model.

2. Line Based Transformation Model (LBTM)

Based on previous research on several HRSI [1],[2] [3] (such as IKONOS and QuickBird), it is possible to assume that sensors move linearly in space with a stable attitude. Thus, if a projection coordinate system is adapted as a reference system, the orientation angles can be regarded as constant and the flight path of the satellite as approximately straight. Under these assumptions, the conformal and the affine models (equation (1) and (2)) present successfully the relationship between points in image and object space [4]. That means the disturbance in the image space is a function of scale, rotation and translation of the object space, which become the base in establishing the new model.

The conformal model:

$$x_1 = b_1 X_1 - b_2 Y_1 + b_3$$
$$y_1 = b_4 X_1 + b_5 Y_1 + b_6 \qquad (1)$$

where x,y are image coordinates, X,Y are the ground coordinates, and $b_1,\ldots,b_6$ are the conformal model coefficients.

The affine model:

$$x_1 = c_1 X_1 + c_2 Y_1 + c_3 Z_1 + c_4$$

$$y_1 = c_5 X_1 + c_6 Y_1 + c_7 Z_1 + c_8 \quad (2)$$

where x,y are image coordinates, X,Y,Z are the ground coordinates, and $c_1,\ldots,c_8$ are the affine model coefficients.

Lines can be presented in either image or object space by different ways. Intersection between two planes, line descriptors, normal to line descriptors are examples of lines representation. Apart from these methods, a unit vector presents by any two points along the line seems to be the best choice to present line in image or object space. It is quite useful when the point coordinates can be easily obtained from GIS database, hardcopy maps, terrestrial mobile mapping system (using kinematic GPS technique), or manual digitizing [5].

The Line Based Transformation Model (LBTM) suggested in this work is based on the relationship between the unit vector components of the line in the image space and the unit vector components of the conjugate line in the object space. The underline principle in this mathematical model is that the unit vector components in either image and object space could replace the point coordinates in the conformal and affine models presentation.

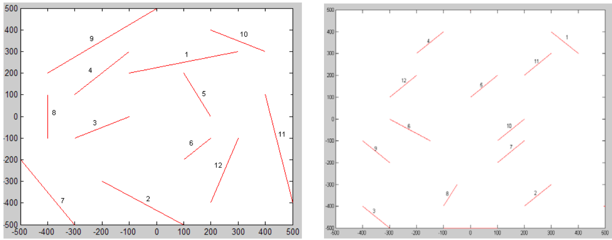
Generally, the unit vector is not a unique representation of line when it can present the line and any parallel lines. In order to overcome this problem when presenting the relationship between the two spaces, the new line based model coefficient values were compared to the ordinary point based model coefficient values. By using several data sets, it was found that scale factor coefficients in both the point-based model and the new model are almost having the same values and the difference is only between the translation terms, which define the exact displacement between the two spaces. Therefore, any single control point can be used to redefine the translation terms and thus, the coefficients of the new line based model can be recovered and used in the point-based models. This finding is significant when it enables users to utilize both lines and points as a control features to determine the image parameters and then they can use them with the ordinary point-based model for rectifying images.

A unique solution for the new model coefficients could be calculated by using three or four lines in conformal and affine line based model respectively and a single control point in order to rectify image. If the number of observations available (number of lines) is more than the minimum amount, then a least square adjustment is used. The new technique has been checked with both synthetic and real data and the results show the applicability of the model under few limitations.

3. Data sets

1) Synthetic Data Set

Two different terrain elevation conditions were simulated for a synthetic imagery by aid of real IKONOS image parameters extracted by using the affine model from real stereo imagery. Forty-eight points are simulated in the object coordinate system in two different terrain type representation and their corresponding image coordinates are calculated. Flat and undulated terrain in 15 and 100 m elevation differences respectively performs basics for four cases to present two different lines configurations in the two different terrain presentations. Twenty-four points from each set of coordinates are used to establish twelve straight lines, which will be used as control lines, and the remaining twenty-four points are used as checkpoints. Figure 1a,b shows the different configurations of the two sets of lines.



a) The first set of lines configuration b) The second set of lines configuration
Fig. 1: The Synthetic data

2) Real Data Set

IKONOS stereo pair over a part of Hong Kong has been mainly used as a high-resolution satellite to test the proposed technique. The area covered by the two images extends 11.60x10.28 km and 6.62x10.18 km with 2.5x10 km overlapped area. The images inclination angles are 19.02 and 27.3 degrees respectively which leads to base to height (B/H) ratio of about 0.87. The maximum ground elevation difference in the test area is about 450 meter. For the field points collection, the fast static GPS technique was used to collect thirty-eight well-distributed GCPs. Further information about the test field can be found in [2] and [3].

For more study on the new technique, two sets of lines connect different observed ground points have been established in order to study the effects of number of lines, length, slope, and elevations. Twelve lines were established in each case and used as control lines and the remaining points (fourteen points) were utilized as checkpoints. The next section reveals summary for the results obtained and accuracy assessment that could be achieved by the new technique.

4. Experimental Results

Four experiments using synthetic data have been performed. Case 1 presents the first lines configuration for the undulated simulated terrain when case 2 presents lines in the same configuration but for the flat terrain. In order to check the effects of the lines length, slope and orientation angles, another set of lines were configured to present case 3 and 4 for undulated and flat terrain respectively. Long lines are presented in case 1 and 2 with different inclination angles when relatively short lines are performed for case 3 and 4. In a second step, real IKONOS images have been used to check the applicability and fidelity of the new approach. Two different lines configurations have been performed connecting the observed GPS points. Case 1 presents synthetic roads on the images when case 2 connects observed points on road intersections that present real roads. The performance of the new approach has been tested with synthetic and real data and the results are summarized in table 1.

From the results obtained, it is obvious that the new model works perfectly in the flat terrain as can be seen from the results in case 2 and 4 of the synthetic data. However, there is some differences in the achieved accuracy in the flat terrain depends on the lines slope. An extensive investigation have been performed and we found that the main effect comes from the lines slope when for instance in case 2, lines have a low slope comparing to lines in case 4, but no considerable effects from the lines orientation or length have been recorded. Accuracy up to half meter can be achieved by both affine and conformal LBTM when this accuracy declined to about 1.5 m when using slightly sharp slope lines. In conclusion, both affine and conformal LBTM are producing accurate results but affine LBTM remains better when it considers the terrain elevation effects on the produced planer coordinates.

By using undulated simulated terrain data, the results reveal acceptable accuracy of less than 3 m in most cases with a modest number of Ground Control Lines (GCLs) depend on the terrain elevation differences and the lines slope. The affine LBTM remain presenting better results as it considers the terrain effects as was explained before. In general, we can state that the rectification results obtained from the synthetic data and LBTM could produce comparable accuracy to point based one with a modest number of GCLs.

To verify the performance of the new approach, the two different sets of simulated and real roads extracted from real IKONOS images have been used. As can be seen from table1 (RealHK case1), increasing the number of GCLs from 4 up to 12 GCLs improves the results but

Table1. Experimental results from synthetic and real data sets.

Data Set		No. of GCLs	No. of Chkpts	Affine LBTM Total RMS (m) X	Y	Conformal LBTM Total RMS (m) X	Y
Synthetic	Case1	4-12	24	5.32- 2.92	2.04- 2.26	3.81- 3.01	6.99- 4.60
	Case2			0.20- 0.21	0.29- 0.23	0.46- 0.28	1.10- 0.51
	Case3			4.32- 3.27	4.21- 2.62	3.96- 2.17	5.77- 6.31
	Case4			2.03- 1.47	1.84- 1.67	3.76- 1.49	1.63- 0.46
Real (HK)	Case1	4-12	14	78.87- 37.99	35.91- 43.94	26.31- 9.53	36.16- 31.13
	Case2			9.01- 2.39	6.96- 2.01	7.73- 5.09	8.19- 9.14

the accuracy is quite poor. Checking the used GCLs reveals that some of the used lines have sharp slope, which is affect the accuracy. By using the real roads (case2) the results accuracy were matching with what we gained by using the simulated data. Accuracy of about 2 m in X and Y directions can be achieved by applying the affine LBTM and 12 GCLs. However, the accuracy declined to about 5 m in X and 9 m in Y by using the conformal LBTM which is consistent with our expectations and results from the simulated data when the conformal LBTM does not consider the terrain elevation differences effects. In each of the cases presented above, the new LBTM approach revealed high performance by using lines as a control features except in case of using sharp slope lines which is normally not the real case when this lines present real roads or artificial features.

5. Conclusions

This research proposed a new Line Based Transformation Model (LBTM), which is based on either linear features only, or linear features with a number of ground control points for high-resolution satellite imagery rectification. The new model does not require any further information about the sensor model or satellite ephemeris data. The underline principle of the proposed model is based on the relationship between line segments of straight lines in the image space and corresponding lines in the object space using an affine or conformal representation. Synthetic as well as real data have been used to check the validity and fidelity of the new approach and the results showed that the LBTM could be used efficiently in HRSI rectification. In future work, the new approach will be extended to cover other types of medium resolution satellites such as IRS and SPOT.

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