DEVELOPING AND IMPLEMENTING LINE-BASED TRANSFORMATION MODELS TO REGISTER SATELLITE IMAGES

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ABSTRACT:

Advances in remote sensing technologies demonstrated the capability to acquire high quality metric information from satellite images. The IKONOS satellite image, for example, has a pixel size of one meter. The sensor model parameters are not yet released. This motivate the use of empirical transformation models to represent the relationship between image space coordinates and object space coordinates. Most of the employed transformation models are based on point features. However, these transformation models could be driven using linear features. Linear features are easier to digitize than point features and they improve both the geometric strength and the redundancy of the adjustment model. This research investigates the rectification of a single Geo panchromatic IKONOS image using different line-based transformation models. Experiments are conducted using the 2D line-based transformation models using 6 and 8 parameters and the line-based DLT model. Different sets of ground control lines are tested. Results showed that less than two meters horizontal RMSE could be achieved. In addition, insignificant differences are noticed between the transformation parameters computed using the point-based and the line-based transformation models. Results are compared with those of point based transformation model and they are stable.

1. INTRODUCTION

The recent introduction of IKONOS and other high-resolution commercial satellite imaging systems has initiated a new era for large scale mapping. Space Imaging provides a number of IKONOS image products with different processing levels including the Geo, Reference, Pro, Precision and Precision Plus products that have corresponding absolute positioning accuracy Root Mean Square Error (RMSE) of 25, 11.8, 4.8, 1.9 and 0.9 meters, respectively [1]. Highly accurate products, such as Precision and Precision Plus, are much more expensive than the Geo products. Space Imaging has refused to release information on the sensor model for the IKONOS imaging system, as well the precise in-flight position and the attitude data of the imaging sensor. The orientation information of IKONOS images is available in the form of a so-called Rational Functions (RF) model. Recently, several 2D and 3D transformation models have been employed to register IKONOS stereo images using different sets of ground control points. Different investigations reported that the rectification of a single Geo panchromatic IKONOS image using point features could achieve the required accuracy for large scale mapping. Most of these investigation are done using point features.

Recently, line based modelling has stimulated a great interest. Different investigation have been done on the use of linear features in digital photogrammetry. The advantages of employing linear features in digital photogrammetry is summarized in [2]. Linear features add more information, they have higher semantic than point features, and they are easier to detect than point features. Geometric constraints are more likely to exist among linear features. This will eventually improve the adjustment process. Moreover, linear features have the advantage that they can be defined by segments. They can be easily delineated in digital images either manually or automatically. Corresponding ground space lines could be identified from digital maps, GIS layers, or by GPS surveying techniques.

This research investigates the potential of using straight lines to rectify a single IKONOS Geo panchromatic image. The line-based 6 parameters transformation model, the 8 parameters transformation model, and the Direct Linear Transformation (DLT) model are presented and examined. Different sets of Ground Control Lines (GCLs) are generated and tested. Checklines and checkpoints are used to evaluate the rectification process. Results showed an RMSE of about one meter using line based transformation models using either 6 or 8 parameters with 6 GCLs. The DLT model showed an RMSE of about two meters. The results were stable and showed insignificant differences between different sets of GCLs. In addition, the results are compared with the results of the point-based transformation models and insignificant differences between the parameters are noticed.

2. BACKGROUND

Recent advances in mapping technology satellite have produced high resolution satellite imaging systems. Mapping systems based on high-resolution satellite images are increasing. The accuracy of these systems is still under investigation. Researchers mainly focus on the analysis and assessment of using point based transformation models in the rectification of satellite images. For example, the use of the Rational Polynomial Coefficients (RPCs) to model the IKONOS sensor using ground control is investigated in [3] and [4].

A number of investigations have been reported concerning the accuracy attainable by various methods of processing IKONOS stereo images. For example, a full suite of new methods and software package SAT-PP (Satellite Image Precision Processing) for the precision processing of satellite images is developed and evaluated in [5]. In addition, a 3-D transformation model, based on the collinearity condition, is used in [6] to generate orthophotos from IKONOS stereo images using 1 meter to 20 meters DEMs. Results reported an accuracy of 2 to 4 meters using 13 panchromatic and multispectral IKONOS images over seven test sites.

A large amount of research has been devoted to efficiently improve the accuracy of the spatial data generated using the satellite imageries. For example, different methods are presented in [7] to improve the accuracy of the ground coordinates using IKONOS stereo images with Ground Control Points (GCPs) by either refining the vendor-provided IKONOS Rational Function Coefficients (RFCs) or refining the derived ground coordinates. The accuracy of the 3D ground point coordinates was improved to 1 to 2 meters after the refinement. The same results were obtained [8] after removing the systematic errors in the computed coordinates. In addition, results in [9] showed an improved planemetric accuracy of 0.3–0.6 meter and elevation accuracy of 0.5–0.9 meter using less than 10 GCPs after removing the biases in the RPCs. Several researchers investigated the potential of rectifying a single IKONOS panchromatic images. The use of a single Geo panchromatic IKONOS image for large-scale mapping is evaluated in [10], [11], [12] and [13]. The results recommended that IKONOS images could be used to provide 1:10000 scale maps. In addition, the results suggested using IKONOS panchromatic images to provide preliminary and provisional versions of 1:5000 scale maps.

Additional investigation has been conducted to rectify IKONOS images using linear features. The 2D and 3D affine and conformal transformation models are used to model the relationship between object space and image space linear features in [14]. The underlying principle of the models is that the line unit vector components of a line segment could replace the point coordinates in the representation of the ordinary 2D and 3D affine and conformal models. Experiments with synthetic and real data were conducted. For the real data, a group of 12 GCLs were established by connecting some GCPs in the data set. A set of 16 GCPs were used as checkpoints. Results showed an average RMSE of several meters in the X and Y coordinates of the check points using 4 to 12 GCLs.

Several forms, based on point features and line features, of the projective transformation model are used to rectify different satellite images in [15]. These images include LANDSAT7, SPOT4, IRS-1D, IKONOS images. For the LANDSAT7, results showed an RMSE of about 16 meters using either the point- or line- based projective transformation models. For SPOT4, results showed an RMSE of about 13 meters. For the IRS-1D, results showed an RMSE of about 8 meters. For IKONOS, results showed an RMSE less than 2 meters. In all experiments, the combined point/line-based projective transformation model showed approximately the same results as the point- and line-based projective transformation models.

Straight lines are used in [16] to register multi-source satellite images including IKONOS, Quickbird, Orbview, and SPOT-5. Results showed that the 6 parameters transformation model can be used to register satellite images with narrow angular filed of view. In addition, the results showed that the 2D similarity transformation model could be used in low accuracy applications.

3. LINEAR FEATURES BASED TRANSFORMATION MODELS

Many photogrammetric models have been developed based on point features. However, image information can be represented in other forms such as linear features. Linear features are relatively easier to detect and extract from digital images than point features. Hence, photogrammetric models need to be expanded to accommodate linear features. In this case, given two corresponding linear features in two different spaces, the relation between the parameters of the two linear features are derived rigorously using the transformation parameters between the two spaces. Straight lines in a 2D space is characterized by two independent parameters [17]. These two parameters could be formulated using different representations. For this research, the linear feature is characterized using equation 1. However, the equation is not valid for a straight line passing through the origin.

$$ax + by + 1 = 0 \tag{1}$$

Where x and y are the planemetric coordinates of any point on the line, and a and b are the line parameters.

3.1 Six Parameters Transformation

The line-based 6-parameter transformation model is described using equation (2).

$$a_1 = \frac{a_2 p_1 + b_2 p_4}{a_2 p_3 + b_2 p_6 + 1} \qquad b_1 = \frac{a_2 p_2 + b_2 p_5}{a_2 p_3 + b_2 p_6 + 1} \tag{2}$$

where p_1, p_2, p_3, p_4, p_5 and p_6 are the 6 transformation parameters,
a_1 and b_1 are the line parameters in space 1.
a_2 and b_2 are the line parameters in space 2.

3.2 Eight Parameters Transformation

The line-based 8-parameters transformation model can be described using equation (3).

$$a_1 = \frac{a_2 p_1 + b_2 p_4 + p_7}{p_3 + p_6 + 1} \qquad b_1 = \frac{a_2 p_2 + b_2 p_5 + p_8}{p_3 + p_6 + 1} \tag{3}$$

where p_1, p_2, p_3, p_4, p_5, p_6, p_7, and p_8 are the 8 transformation parameters,
a_1 and b_1 are the line parameters in space 1.
a_2 and b_2 are the line parameters in space 2.

3.3 Direct Linear Transformation

The point-based DLT transformation model is described using equation (4).

$$x_2 = \frac{p_1 x_1 + p_2 y_1 + p_3 z_1 + p_4}{p_9 x_1 + p_{10} y_1 + p_{11} + 1}$$
$$y_2 = \frac{p_5 x_1 + p_6 y_1 + p_7 z_1 + p_8}{p_9 x_1 + p_{10} y_1 + p_{11} + 1} \quad (4)$$

where x_1, y_1, z_1, x_2, y_2 and z_2 are the point coordinates in space 1 and 2,
$p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}$, and p_{11} are the DLT parameters.

Substituting the values of x_2 and y_2 equation 1 can be written as:

$$a_2\left(\frac{p_1 x_1 + p_2 y_1 + p_3 z_1 + p_4}{p_9 x_1 + p_{10} y_1 + p_{11} + 1}\right) + b_2\left(\frac{p_5 x_1 + p_6 y_1 + p_7 z_1 + p_8}{p_9 x_1 + p_{10} y_1 + p_{11} + 1}\right) + 1 = 0$$

After grouping similar coefficients and normalizing:

$$\frac{a_2 p_1 + b_2 p_5 + p_9}{a_2 p_4 + b_2 p_8 + z_1(a_2 p_3 + b_2 p_7 + p_{11}) + 1} x_1 + \frac{a_2 p_2 + b_2 p_6 + p_{10}}{a_2 p_4 + b_2 p_8 + z_1(a_2 p_3 + b_2 p_7 + p_{11}) + 1} y_1 + 1 = 0$$

Hence, the relationship between (a_1,b_1) and (a_2, b_2) can be obtain as shown in equation (5). However, it should be noticed that one Z value is used to represent the elevation of the line. This implies that only horizontal lines should be used. Or an average elevation for the line should be used.

$$a_1 = \frac{a_2 p_1 + b_2 p_5 + p_9}{a_2 p_4 + b_2 p_8 + z_1(a_2 p_3 + b_2 p_7 + p_{11}) + 1}$$
$$b_1 = \frac{a_2 p_2 + b_2 p_6 + p_{10}}{a_2 p_4 + b_2 p_8 + z_1(a_2 p_3 + b_2 p_7 + p_{11}) + 1} \quad (5)$$

where $p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}$, and p_{11} are the DLT parameters,
a_1 and b_1 are the line parameters in space 1.
a_2 and b_2 are the line parameters in space 2.

4. EXPERIMENT RESULTS AND ANALYSIS

4.1 Dataset Description

In this paper, the line-based transformation models presented in section 3 are used to rectify the IKONOS image. The proposed technique uses only linear features for the rectification process. In this research a single Geo panchromatic IKONOS image is used. Although the GEO panchromatic image is provided with a pixel size of one meter, the absolute positioning accuracy is about ±15 meters. GCLs are established using 12 GCPs. The points were surveyed using two dual-frequency, Trimble 4000SS, GPS receivers. The GCPs are used to generate independent sets of GCLs, check-lines, and check-points. For each line, an average elevation is computed and used to represent the elevation of the entire line.

4.2 Experiments

Several experiments are conducted to rectify the IKONOS image using the transformation models presented in section 3. Different combination of GCLs, check-lines, and check-points are tested. In the first experiment, four GPS points are used to generate 6 GCLs. The remaining eight GPS points are used as check-points and are also used to generate check-lines. The distribution of GCLs, check-lines, and check-points is shown in figure 1. In the second experiment, five GPS points are used to generate 10 GCLs. The remaining GPS points are used for the checking process. A third experiment was conducted using 15 GCLs. For each experiment, the transformation parameters of each model are computed using the least squares adjustment technique. For each pair of corresponding image line and ground line, two observation equations are written. The entire system of equations is then solved iteratively due to it's non-linearity. Approximate values for the transformation parameters are initially used to compute the correction to these approximate values. The corrected parameters are used to compute the line parameters (a and b) of the check-lines. In order to facilitate the analysis of the results, the (a and b) parameters are converted to the (p and α) parameters. The parameter (p) is defined as the length of the perpendicular from the origin to the line, while (α) is the angle measured counter-clockwise from the positive x-axis to that perpendicular.

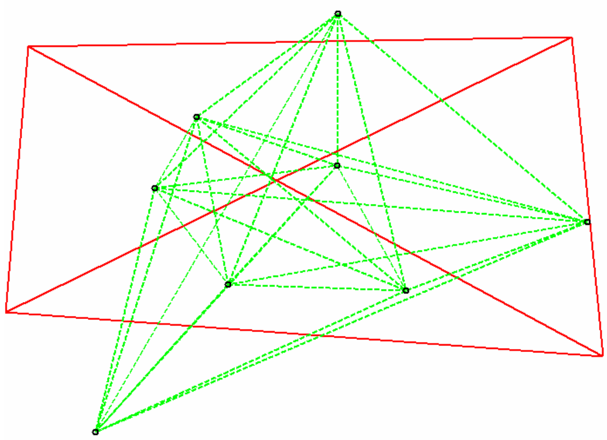

Figure 1. GCLs (continuous), check-lines (doted), and check-points (o)

4.3 Result Analysis

Table 1 shows the results of the conducted experiments using the presented transformation models. The table shows the RMSE of the (p and α) for the check-lines. The results show that the RMSE in (p) is less than one meter. In addition, the RMSE in (α) is about .05 degree. The X and Y RMSE for the check points are less than 1.5 meters for both the 6 and 8 parameters transformation models. The RMSE for the DLT model is larger because the GCLs are not horizontal.

	Number of GCLs	RMSE (p)	RMSE (α)	RMSE (X)	RMSE (Y)
6 parameters	6	0.56m	0.049 °	0.91m	1.26m
	10	0.34m	0.052 °	1.03m	1.06m
	15	0.30m	0.052 °	1.03m	1.04m
8 parameters	6	0.50m	0.061 °	1.10m	1.34m
	10	0.48m	0.066 °	1.17m	1.03m
	15	0.47m	0.066 °	1.15m	1.03m
DLT	10	0.94m	0.042 °	2.16m	1.73m
	15	0.90m	0.045 °	1.77m	1.01m

Table 1. RMSE for check-lines and check-points

In order to test the stability of the estimated parameters, another experiment is conducted using the 6 parameters transformation model with different sets of GCLs. For each experiment, the transformation parameters are computed. Results in table 2 shows the minimum, maximum, and mean values of the calculated transformation parameters. In addition, table 2 shows the transformation parameters calculated using the point-based 6 parameters transformation model with all the 12 GPS points used as GCPs. The table shows that the differences between the mean values of the transformation parameters and the point-based transformation parameters are insignificant. Table 3 shows the statistics for the differences in the parameters of the 8 parameters transformation model using different sets of GCLs and the values computed using the point-based transformation model.

	Min	Max	Mean	Point-based
a1	0.8840	0.8811	0.8827	0.8827
a2	-0.0020	-0.0075	-0.0041	-0.0043
a3	0.6913	-1.3231	0.0163	0.000
a4	0.0529	0.0514	0.0522	0.0520
a5	0.9150	0.9131	0.9138	0.9146
a6	0.1972	-0.4049	0.0319	0.000

Table 2. Statistics for the differences in the parameters of the 6 parameters transformation model using different sets of GCLs

	Min	Max	Mean	Point-based
a1	0.881	0.883	0.882	0.882
a2	-0.007	-0.001	-0.004	-0.004
a3	-1.283	0.685	0.025	0.431
a4	0.051	0.530	0.052	0.052
a5	0.913	0.914	0.913	0.914
a6	-0.516	0.332	0.023	0.074
a7	0.000	0.000	0.000	0.000
a8	0.000	0.000	0.000	0.000

Table 3. Statistics for the differences in the parameters of the 8 parameters transformation model using different sets of GCLs

5. CONCLUSIONS

This research presents the potential of using straight lines to rectify a single panchromatic IKONOS image. The research showed the process of developing the line-based 2D transformation models. In addition, the research investigates the use of the line-based 6-parameters, 8-parameters, and DLT transformation models to rectify panchromatic IKONOS images. Results showed less than 1.5 meters RMSE in the horizontal direction using 6 to 15 GCLs. Moreover, the results showed that the computed parameters are stable and equivalent to the parameters computed using the point-based transformation models and the differences are insignificant. The results suggest the use of linear features to rectify IKONOS images and other high-resolution satellite images such as QuickBird. This will allow reducing the number of ground control points and will eventually reduce the time and cost of the surveying effort.

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