EVALUATION OF LBTM FOR HRSI RECTIFICATION

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ABSTRACT:

At present, HRSI (High-resolution Satellite Imagery) is more and more widely applied for surveying, land, constructing, production and living field, and it becomes increasingly important to acquire orthophotograph by processing geometric rectification of satellite original images. Less or without GCPs (Ground Control Points) in several parts of area is a puzzled problem for remote sensing imagery rectification. In this paper a three-dimensional affine transformation, 3D affine LBTM (Line Based Transformation Model) is introduced, and is applied to achieve geometric rectification based on a set of artificial data which used to evaluate the feasibility of this developing model for different terrains and the number, density, elevation, slope, distribution and attitude requirement of linear features.

1. INTRODUCTION

At present, HRSI is becoming more and more extensively applied for urban planning, surveying, mapping, land management, agriculture and military field. Digital orthophotoimagery is the base of constructing basic service of national spatial data and digital earth. And it becomes increasingly important to acquire orthophotoimage by processing geometric rectification of satellite images.

When we rectify the satellite image, the most important step is selection of ground control points. General speaking, control points should have the following characteristics: ground control points have obvious, clear position signs on the image; features on the GCPs do not variance along with time; selecting GCPs on the original image must base on the same terrain height; GCPs should well-proportioned distribute on the whole image; and should have quantitative ensure (Zhao, Y. S. (2003)). But in some unfrequented areas of China, especially Western China, there are not enough ground control points or control points are not well distributed on the image, and on the high-resolution remote sensing image, control points are not obvious and not easy to find out, so other methods need to be tried.

Here, a new non-rigorous mathematics model, Line base transformation model is a suitable way to solve these problems. LBTM achieves image rectification base on line, such as river, road, bounding wall, slope, bank and ridge etc. if these line information also clear and well-proportioned distribute on the whole image, and do not variance along with time, these information can instead ground control points for image rectification in theory. This method developing, can change only use control point information for image rectification in current production, increase using rate of remote sensing image.

After the principle introduction of this developing model, some set of three-dimensional coordinate data are assumed to analyze the feasibility of one of the familiar LBTM, three-dimensional affine LBTM, which is used for three different terrains: flat terrain, hilly terrain and mountainous terrain.

2. LBTM

According to the principle analysis, practice and research for numbers of years (Shaker, A. and Shi, W. Z. (2003)), it is obvious that linear feature can be used rigorous mathematical models and points can be applied to non-rigorous mathematical models. That leads to the question of "Can linear features be used with non-rigorous mathematical models in order to circumvent the absence of satellite information and maintain satisfactory results?" The research by Shaker, A. and Shi, W. Z. (2004) answers the question with the development of a new model named the LBTM.

With the LBTM, most of the problems of using linear features with rigorous models have been overcome. It is a very simple model which is time independent, can be applied to images from any linear array sensor, does not require any information about sensor calibration or satellite orbit, and does not require any initial approximation values.

2.1 The Principle of LBTM

The model can define the image transformation parameters either to use single linear features or to use linear features plus a number of control points. The basic principle of the model is that the relationship between line segments of straight lines on the image space and the object space can be expressed by conformal or affine transformation relationships (Shaker, A (2004)).

Successful exploitation of linear features for image rectification and terrain modelling requires consideration of the following two major sides: the mathematical description of linear features in image and object space and the mathematical description of the relationship between the two spaces. There are different ways for representing linear features in image

space and object space. Straight lines, circles, ellipses and free form lines are examples of such representation. In this research, straight lines as well as free form lines converted center passing through a point on the image line must intersect the object line. In their approach, the standard point-based photogrammetric collinearity equations were replaced by line-circle based ones. Instead of the regularly used two collinearity equations, a single equation is established to ensure the coplanarity of a unit vector defining the object space line, the vector from the perspective center to a point on the object line, and the vector from the perspective center to a point on the image line. Furthermore, coordinate transformations are implemented on the basis of linear features. In this case, feature descriptors are related instead of point coordinates (Shaker, A (2004)).
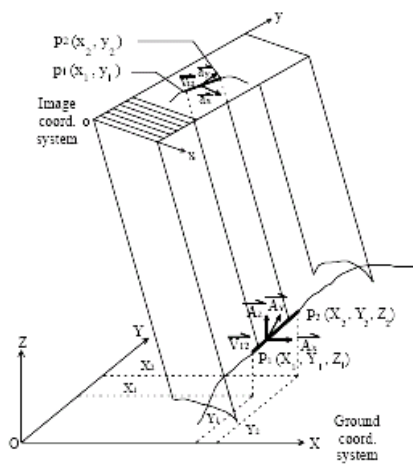
2.2 3D Affine LBTM

Figure 1: Unit line vector representation in image and object space (case of linear array sensor) (Adopted from Shaker, A. 2004)

Vectors $\vec{v}_{12}$ and $\vec{V}_{12}$ are unit vectors for conjugate lines in image and object space respectively (Figure 1). Any two points along the line segment in image and object space can define the two unit vectors. Suppose that point $p_1 = (x_1, y_1)$ and $p_2 = (x_2, y_2)$ are two points on the line in image space, then $\vec{v}_{12}$ can be presented in matrix form as:

$$\vec{v}_{12} = \begin{bmatrix} a_x & a_y & 0 \end{bmatrix}^T \qquad (1)$$

where

$$a_x = \frac{x_2 - x_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \quad \text{and} \quad a_y = \frac{y_2 - y_1}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$$

On the other hand, suppose that points $P_1 = (X_1, Y_1, Z_1)$ and $P_2 = (X_2, Y_2, Z_2)$ are located on the conjugate line in the object space. Then, the unit vector $\vec{V}_{12}$ is:

$$\vec{V}_{12} = \begin{bmatrix} A_X & A_Y & A_z \end{bmatrix}^T \qquad (2)$$

where:

$$A_X = \frac{(X_2 - X_1)}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}}$$

$$A_Y = \frac{(Y_2 - Y_1)}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}}$$

$$A_Z = \frac{(Z_2 - Z_1)}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}}$$

It is worth to mention that points p_1, p_2 and P_1, P_2 on image and object spaces are not conjugate points, but the lines they lie on are conjugate lines. As was mentioned earlier, the relationship between image and object space can be represented by 3D affine transformation for high-resolution satellite imagery. The same relationship between the two coordinate systems is used to represent the relationship between vectors in image and object space. Any vector in object space can be transformation into its conjugate vector in image space by applying rotation, scale, and transformation parameters as shown in equation (4.3):

$$\vec{v} = M \lambda \vec{V} + T \qquad (3)$$

where $\vec{v}$ and $\vec{V}$ are vectors of line segment in image and object space respectively, M is a rotation matrix relating the two coordinate systems, λ is a scale matrix (a diagonal matrix providing different scales in different directions), and T is a transformation matrix.

The elements of M are functions of three sequential rotations about the X, Y and Z (object) coordinate axes and are the same as used in the derivation of the collinearity equations used in photogrammetry. Substituting the various presented matrices into equation 3 gives:

$$\begin{bmatrix} a_x \\ a_y \\ 0 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} A_X \\ A_Y \\ A_Z \end{bmatrix} + \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} \qquad (4)$$

where λ_1, λ_2, λ_3 are scale factors, m_{11}, $m_{12}, \ldots, m_{33}$ are the rotation matrix elements, (a_x, a_y) are the line unit vector components in the image space coordinate system, (A_X, A_Y, A_Z) are the line unit vector components in the object space coordinate system, and T_X, T_Y, T_Z are the components of the transformation matrix between the image and the object coordinate systems in X, Y and Z directions. The previous form is valid only if the scale factor is equal to ± 1 since the transformed vectors, in this case, are unit vectors. This condition is necessary and should be sufficient to validate the equation. Then, the equation will lead to the following individual equations

$$a_x = (\lambda_1 m_{11} A_X + \lambda_2 m_{12} A_Y + \lambda_3 m_{13} A_Z) + T_X$$
$$a_y = (\lambda_1 m_{21} A_X + \lambda_2 m_{22} A_Y + \lambda_3 m_{23} A_Z) + T_Y \quad (5)$$
$$0 = (\lambda_1 m_{31} A_X + \lambda_2 m_{32} A_Y + \lambda_3 m_{33} A_Z) + T_Z$$

After substituting the scale factors λ_i multiplied by the rotation matrix coefficients m_{iv}, and the translation components T_{X-Z}, by the new coefficients b_i, the transformation equation can be rewritten as:

$$a_x = b_1 A_X + b_2 A_Y + b_3 A_Z + b_4$$
$$a_y = b_5 A_X + b_6 A_Y + b_7 A_Z + b_8 \quad (6)$$

where b_1 to b_3 and b_5 to b_7 present the rotation and scale factors, and b_4, b_8 are translation coefficients. Equation (6) represents the mathematical form of the 3D affine LBTM.

2.3 Rectification by 3D Affine LBTM

The research in this thesis will apply this 3D affine LBTM for high-resolution satellite imagery rectification, and then evaluate the accuracy of the result. The basic image rectification procedure is studied in Chapter1, and in this section, we will analysis rectification arithmetic using the program language by matlab step by step, and all these arithmetic made by Shaker, A., 2004.

Firstly, determine several ground control points for coefficients calculation and accuracy analysis and numbers of ground control lines for coefficients calculation. Acquire image space 2D coordinates (x_i, y_i) on the image and object space 3D coordinates (X_i, Y_i, Z_i) on the ground. It needs to get two end point coordinates for every GCLs and calculate the length of every line on the image and ground. But these points on the lines need not to be conjugate points between image spaces and object spaces.

Secondly, the parameters will be inversely calculated in the software, the main principle of which is expressed in Equation 4.6 and the whole prudence for arithmetic 3D affine LBTM. Then the eight-parameters will all be computed from the transformation model and the characteristic linear features with the method of least square in the program.

Finally, all the pixels on the image will be defined by new coordinates by 3D affine LBTM. Achieve the image rectification. Accuracy analysis will process by root mean square of ground coordinates for GCPs.

3. TEST ARTIFICAL DATA

LBTM is a new kind of non-rigorous mathematics transformation model, the stability and adaptability for different kinds of terrain, different linear feature attitude and distribution need to be considered first, so the date for practice must be relative perfect, the error must in tolerance range and can be evaluated. And the accuracy influence will be claimed mainly come from forecasted errors and transformation model. Due to the reasons above, artificial data is needed first for this project.

Data sets covering a 10×10 square kilometers area were simulated to test the developed mathematical model discussed in this paper. Three different elevations of terrain conditions were established for the artificial data. The first condition was simulated for flat terrain by an elevation difference of less than 50m. The second condition was simulated for hilly terrain by an elevation difference of about 500m. The third condition was simulated for mountainous terrain by an elevation difference over 1000m. Thirty well-distributed ground points were established for every condition in the object coordinates system. The three groups of the ground points for three conditions of terrain were considered to have the same planimetric locations and the only difference for them was in their elevations. The original coordinates of the four corners are clockwise: (10km, 10km), (10km, 20km), (20km, 20km), (20km, 10km). Figure 2 shows the distribution of the ground points in plane, which is made in autoCAD interface, while Figure 3, a b and c shows the three different terrain shapes of the artificial data.
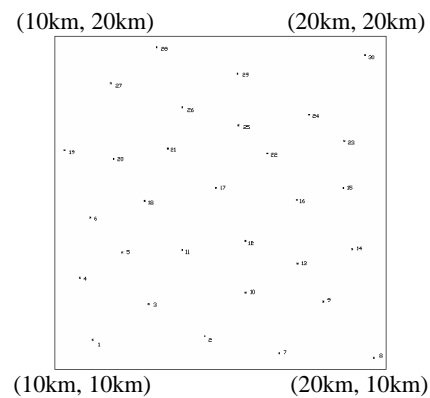

Figure 2: Distribution of the artificial ground control points in a plane

(a)Flat terrain

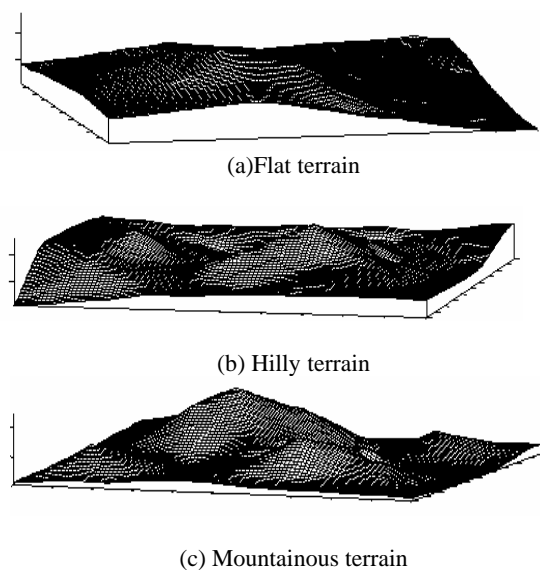(b) Hilly terrain

(c) Mountainous terrain

Figure 3: Three different terrain shapes of the artificial data

Given the image parameters which have calculated by the true IKNOS and SOPT imageries using the affine model and the ground coordinates for the artificial points, (transformation parameters is given by experiments of Ahmed Shaker), the image coordinates (x1, y1), (x2, y2) of each point on the stereo artificial imageries were calculated for the three terrain conditions. This means that the data of the image is completely consistent with the ground point coordinate, which is perfect tool for testing 3D affine LBTM. In order to make the artificial data as the real one, the errors were added on both image space coordinates and object space coordinates, which are about 1m to 2m for ground coordinates and 0.5m to 1m for stereo image coordinates.

Two kinds of artificial ground control lines were simulated individually for three conditions of terrain, which are shown in Figure 4: parallel lines and random lines. So there will be total six models here, three terrains, and every terrain have two kinds of line attitudes. Fifth well-distributed ground control lines of every kind were established for three condition in the object coordinate system, the coordinates of two end points on the lines was estimated in the software of Arcmap. After creating TIN in Arcmap according to the distribution and coordinates of the aritificial GCPs and overlapping the line layer on the created TIN, the coordinates of the end points of lines will be simulated on that interface. The lengths for parallel lines for three conditions of terrains were from about 110 meters to 1300 meters and for random lines were from about 130 meters to 1500 meters. The coordinates for the GCLs of stereo images are also calculated by parameters as the GCPs, and add errors individually. These six models will evaluate the terrain and attitudes of lines influence for the accuracy of 3D transformation model, the part of GCPs will be considered as the checkpoints for the final accuracy analysis.
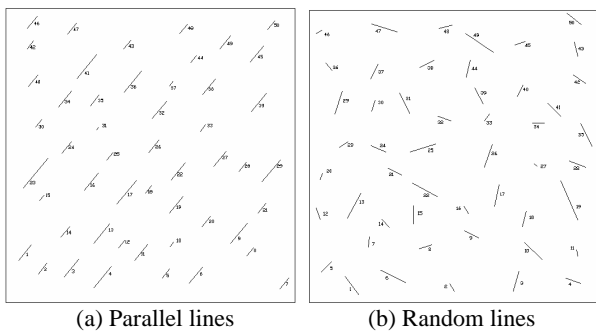

(a) Parallel lines　　　　(b) Random lines

Figure 4: Distribution of the artificial ground control lines

4. EXPERIMENT RESULT AND ANALYSIS

4.1 Results of the artificial data

As introduced in third part, six sets of artificial stereo image data were derived from the actual orientation parameters of three pairs of IKONOS and SPOT imageries for three conditions of terrain and artificial object coordinates of 30 well-distributed points individually. The established GCLs for the different attitudes and terrain of artificial data sets are presented in Figure 4. The results of root mean square (RMS) error for X, Y, Z direction on the ground, when use different numbers of GCLs, have been calculated by the software of 3D affine LBTM in Matlab database, which is written and performed by Ahmed Shaker (2004).

For the results obtained, the results of three sets of artificial data cannot be calculated. There are two types of lines distribution for every condition of terrain, but the results of one of these types cannot be computed by the software for 3D affine LBTM arithmetic. The three sets of artificial data are parallel lines, only the type of random line for the three conditions of terrain can be calculated in the software, and obtained results for RMS errors.

So for the artificial data sets, only three groups of results can be compared for different conditions of terrain, flat, hilly and mountainous terrain. The lines attitudes influence of data sets for the model cannot be discussed in this research. The results of this developed model of artificial data for random lines of terrain conditions are listed in Table 1. The numbers of checkpoints of every terrain are all 30 points, and the numbers of ground control lines are increased from 4 lines (at 4 corners of test-area) to 50 lines, after changing the order of lines, which makes lines well-distributed on the artificial area when selection numbers of GCLs, the RMS errors are obtained adding every two lines from four to fifty lines. And the RMS errors range is listed here from the RMS errors for three different directions of ground coordinate using four lines to using fifty lines.

Terrain condition	No. of GCLs	No. of Chkpts	RMS errors (m)		
			X	Y	Z
Flat	4-50	30	9.95 - 0.78	5.39-2.53	15.76-3.61
Hilly	4-50	30	4.55 - 0.90	0.95 - 2.42	4.19 - 0.57
Mountainous	4-50	30	8.13 - 3.19	20.59 - 5.03	7.66 - 6.14

Table 1: Results of the 3D affine LBTM of artificial data

As showed in the table, when the numbers of GCLs reach to a certain numbers, the RMS errors are nearly in tolerance. The next part 4.2 will discuss the effects of the increasing of ground control lines, and comparing the result of different conditions of terrain for three different ground directions and the result of different ground directions for three different conditions of terrain.

4.2 Compare of different directions of ground coordinate

The research for rectification effects of different terrain conditions will be discussed by the comparing of X, Y and Z directions of ground coordinates. As showed in Figure 5, the trends of RMS errors with the increasing of the numbers of GCLs in different directions are described for every conditions of terrain. For every condition of terrain, various trends of RMS errors with the increasing of the numbers of GCLs are presented with different colours in different directions. With the increasing of the numbers of GCLs from 4 to 50, the various trends of RMS errors are becoming flat and mild when the lines' number reach to a specifically value.

For the flat terrain, the maximum RMS error of the three directions is over 15m, this value is similar to the requirement of tolerance. Behind the numbers of GCLs from 4 to 12, the various of the trend line of three directions is relative sharp, especially for the numbers of 6, the RMS errors can be less then 5m on all the three directions when the numbers of GCLs more than 14, after the GCLs number over 28, the trends of lines are mildest. As shown in Figure 5a, the lowest line is the

blue one, so the rectification accuracy in X direction is relative high for flat terrain. The trend and value of yellow line is closed to the red on, but the yellow one is the direction of Z, which has the highest requirement of accuracy, Z direction for flat terrain not absolutely reach the requirement of accuracy when the numbers of GCLs increase to 50.

For the hilly terrain, the maximum RMS error for the three directions is less than 10m, this value is in the requirement of tolerance for X and Y directions. Only the numbers of GCLs from 4 to 8, the various of the trends line of three directions are relative sharp, and the various for Z direction is relative obvious, the RMS errors can less than 4m on all the three directions when the numbers of GCLs more than 24. As shown in Figure 5b, the lowest line is also the blue one when the GCLs number less than 48, but when the numbers over 48, the smallest error is the Z direction. The RMS errors for all the three directions are in tolerance until the numbers of GCLs over 20.

(a) Results of flat terrain

(b) Results of hilly terrain
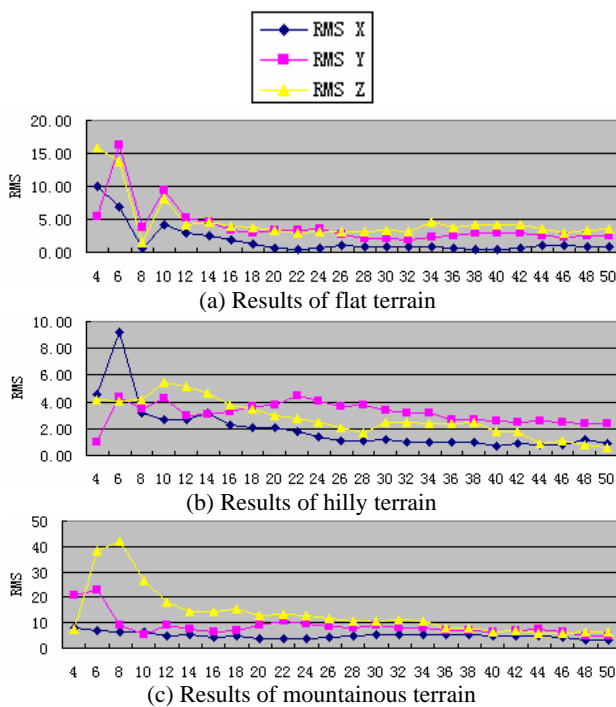

(c) Results of mountainous terrain

Figure 5: Effects of the number and the slope of the GCLs on the three conditions of terrain accuracy of the assumed data using 3D affine LBTM

For the mountains terrain shown in Figure 5c, the maximum RMS error for the three directions is over 40m, this value is higher than the requirement of tolerance. For X direction, the maximum RMS errors is less than 10m, in the requirement of tolerance for mountainous terrain. For the Y direction, when the numbers of GCLs from 4 to 8, the variety of the trend line is sharp, and the maximum value of RMS error is about 25m. After the GCLs numbers reach to 8, the trend become mild and has high accuracy. The various for Z direction is violent, the maximum error is over 40 when use 8 ground control line. Until the numbers of GCLs reach to 36, the RMS error reaches to a perfect value for the accuracy of rectification. Because of the difference of elevation for mountainous terrain is over 1000m, the elevation influence for accuracy of the model is higher than the other two directions.

4.3 Compare of different conditions of terrain

For different conditions of terrain, the accuracy influences will have some differences. This section will compare and discuss the accuracy differences of three conditions of terrain in three ground directions. The comparing of various trends for terrain condition in X, Y and Z direction is shown in Figure 6 respectively.

As presented in Figure 6a, b and c, the trend lines of RMS errors of flat and hilly terrains are nearly overlapping in all the ground directions, it is to say when the errors range influence of coordinates in object space and stereo image space are similar to each other, the accuracy of rectification for flat and hilly terrain have little difference until the numbers of GCLs reach to standard numbers.

(a)   Results of X direction

(b)   Results of Y direction
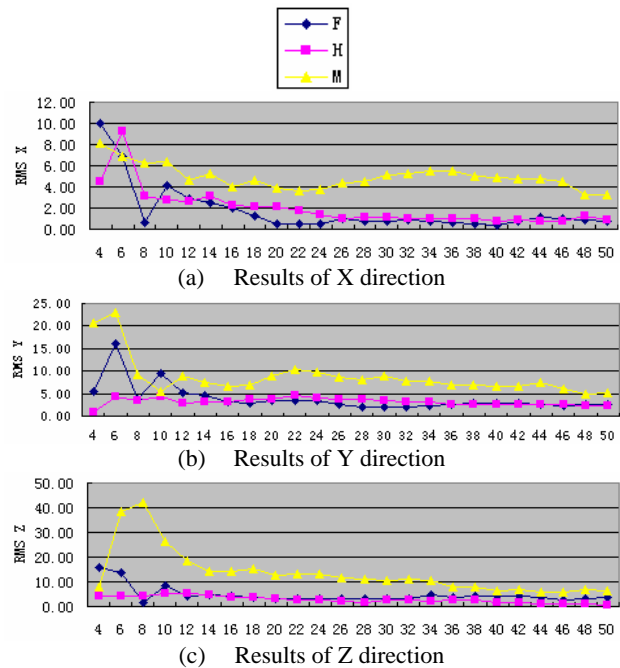

(c)   Results of Z direction

Figure 6: Effects of the number and the slope of the GCLs on the three directions on the ground accuracy of the assumed data using 3D affine LBTM

And the trend lines of RMS errors of mountainous terrain are higher than the other two, the accuracy of rectification is higher when the maximum difference of ground elevation is over 1000m and the slope of GCLs is increasing. The trend various speed of the mountainous terrain is slower than flat and hilly terrain, so the mountainous terrain needs more GCLs to reach to the requirement. On the other hand, because of the same errors range for original artificial data, the mountainous and hilly might higher in the real data sets.

5. CONCLUSIONS

After computation and analysis above, the conclusions on the result from artificial data can be obtained as followed:

1)   3D affine LBTM can be used as rectification model for different conditions of terrain when the GCLs density reach to 50 every 10×10 square kilometers area, the

RMS errors of checkpoints are in tolerance of requirement of accuracy of rectification for the high-resolution satellite imagery.

2) The result for 3D affine LBTM cannot be calculated when the GCLs are all parallel in the whole rectification area. For the program of model cannot run while the GCLs in the area are parallel lines.

3) With the increasing of numbers of well-distributed GCLs, the result of RMS errors of checkpoints trend to stable, after the numbers of GCLs reach to a specifically value, rectification can be achieved.

4) For different conditions of terrain, the density requirement of GCLs is different: flat terrain and hilly terrain need less numbers of GCLs than mountainous terrain to obtain the requirement of accuracy using the same area. In this practice, the requirements of GCLs' number for flat, hilly and mountainous terrains respective are 28, 24 and 36. The stability of program has to improve to reduce the necessary numbers of GCLs.

5) Flat terrain and hilly terrain have similar accuracy of rectification by this developed model, RMS errors of mountainous terrain are higher, which the difference of elevation is over 1000m in 10×10 square kilometers area. And with the variety of conditions of terrain, the variety of RMS errors of checkpoints in Z direction is the most obvious.

6) Not only the terrain will affect the accuracy of the results but also other characteristics of GCLs. Such as the precise data acquisition and data resource which impact the result of flat terrain in Z direction.

7) 3D affine LBTM has nearly the same effect as Points-based transformation model, but needs more lines than points, which can be applied for real data sets and feasibility analysis in Western China after data acquirement.

References

Zhao, Y. S. (2003). *Chapter 6: Interpretation and processing of remote sensing image. Principles and methods for application analysis of remote sensing.* China: Science press.

Shaker, A. and Shi, W. Z. (2003). *Polynomial models as a tool for mapping high-resolution satellite imagery*, European remote sensing conference (SPIE), Barcelone, Spain, on CD Rom.

Shaker, A., Shi, W. Z. and Emam, H., (2003). T*he use of empirical methods in topographic map production of IRS-ID images.* Proceeding of the annual conference of American Society of Photogrammetry and Remote Sensing (ASPRS), Anchorage, USA, on CD.

Shaker, A. (2004). *The line based transformation model (LBTM): A new approach to the rectification of high-resolution satellite imagery.* Geo-Imagery Bridging Continents Xth ISPRS Congress, 12-23 July 2004 Istanbul, Turkey Commission 3.

Shaker, A. (2004). *Point- and line-based transformation models for high resolution satellite image rectification.* PhD dissertation, The Hong Kong polytechnic university, 239 pages.

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