KEY TECHNIQUE OF ACCURATE RECTIFICATION FOR REMOTE SENSING IMAGE WITH HIGH RESOLUTION

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Commission III, **WG** III/2

KEY WORDS: Remote Sensing Image, High Resolution, Parameter Calculation, Image Matching, Accurate Rectification

ABSTRACT:

The geo-referenced image with one-meter resolution (GRIOMR) is one of the most basic information in the digital earth. The remote sensing image with high resolution (RSIHR) is the best resource for acquiring the GRIOMR in low costing and sort period. The key technique producing GRIOMR from RSIHR is introduced in this paper, including parameter computation of RSIHR, image matching to creating DTM and fast orthogonal rectification of RSIHR. After the Rational Polynomial Coefficient (RPC) used by IKONOS and QUICKBIRD images and the block adjustment based on RPC parameters are presented, the new, simple and strict geometric model based on affine transformation is described. When there are control points less than 5 in each image, the block adjustment based on RPC parameters could be used. If there are control points more than 4 in each image, the new, simple and strict geometric model based on affine transformation should be applied. For some of RSIHR, the approximate epipolar image pair, after relative registration, remains quite large y-parallax. Therefore, the 2 D relaxation matching should be used in the DTM modelling from RSIHR. Based on DTM and image parameters acquired by block adjustment based on RPC parameters or the model based on affine transformation, the RSIHR can be rectified by fast algorithm. The experimental results with real RSIHR show the strategy introduced in this paper is feasible. Corresponding conclusion and future work are summarized in the final.

1. INTRODUCTION

The geo-referenced image with one-meter resolution (GRIOMR) is one of the most basic information in the digital earth. The remote sensing image with high resolution (RSIHR) is the best resource for acquiring the GRIOMR in low costing and sort period. The key technique producing GRIOMR from RSIHR is introduced in this paper, including parameter computation of RSIHR, image matching to creating DTM and fast orthogonal rectification of RSIHR.

Because of very strong relativity of traditional parameters of the RSIHR, traditional image parameters can't be acquired sometimes. The algorithm of fitting based on reasonable polynomials, proposed by Kratky (Kratky, 1989a and Kratky, 1989b), is used. For example, the IKONOS and QUICKBIRD images are supported by RPC (Rational Polynomial Coefficient) (Z hang et al., 2001). But, the coordinate accuracy computed by them is quite lower in many cases, and some control points are still needed for improving the accuracy. Furthermore RPC/RPB model is too complex. After the block adjustment based on RPC parameters is presented, the new, simple and strict geometric model based on affine transformation is described (Zhang et al., 2002). Only 8 affine coefficients and one slantwise angle need to be determined by control points. Then, the image coordinates can be calculated using ground coordinates and 9 parameters. When there are control points less than 5 in each image, the block adjustment based on RPC parameters, where an affine transform of image coordinates are computed by measured coordinates of control points and their coordinates calculated by RPC/RPB parameters, could be used. If there are control points more than 4 in each image, the new, simple and strict geometric model based on affine transformation should be applied.
For some of RSIHR, the approximate epipolar image pair(Zhang et al., 1989), after relative registration, remains quite large y-parallax. Therefore, the usual 1-D image matching method is not suitable for the approximate epipolar image pair of the RSIHR, including the very efficient relaxation matching (Baltsavias, 1991; Zhang et al, 1992). Instead of the 1 D relaxation matching, 2 D relaxation matching should be used in the DTM modeling from RSIHR. The procedure includes Feature point extraction, approximate value estimation, matching and refining and filter.

Based on DTM and image parameters acquired by block adjustment based on RPC parameters or the model based on affine transformation, the image coordinates can be calculated for the orthogonal rectification of RSIHR. After re-sampling on original RSIHR, the orthogonal image is obtained. The fast algorithm for orthogonal rectification of RSIHR should be applied. The experimental results with real RSIHR show the strategy introduced in this paper is feasible.

2. PARAMETER COMPUTATION OF RSIHR

If there are control points less than 5 in each image, the block adjustment based on RPC parameters could be used. Otherwise the new strict geometric model based on affine transformation could be applied for any RSIHR.

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2.1 Block adjustment based on RPC/RPB parameters

2.1.1 Model of block adjustment: After the ground coordinates (*X, Y, Z*) of a control point are converted to the geographic coordinates (*Latitude, Longitude, Height*), its image coordinates (*s, l*) can be computed:

$$P = \frac{Latitude - LAT\_OFF}{LAT\_SCALE}$$
$$L = \frac{Longitude - LONG\_OFF}{LONG\_SCALE} \tag{1}$$
$$H = \frac{Height - HEIGHT\_OFF}{HEIGHT\_SCALE}$$

$$x = \frac{\sum_{i=1}^{20} a_i \cdot \rho_i(P,L,H)}{\sum_{i=1}^{20} b_i \cdot \rho_i(P,L,H)}$$
$$y = \frac{\sum_{i=1}^{20} c_i \cdot \rho_i(P,L,H)}{\sum_{i=1}^{20} d_i \cdot \rho_i(P,L,H)} \tag{2}$$

$$l = y \cdot LINE\_SCALE + LINE\_OFF \tag{3}$$
$$s = x SAMP\_SCALE + SAMP\_OFF$$

Where the parameters *LINE_OFF*, … , a_i, … are from the RPC parameter file, ρ_i are polynomials (Zhang, 2001). For each point, following equations can be acquired:

$$c = e_0 + e_1 s + e_2 l,\ r = f_0 + f_1 s + f_2 l$$
$$s = g_0 + g_1 c + g_2 r,\ l = h_0 + h_1 c + h_2 r \tag{4}$$

Where (*c, r*) are the measured image coordinates, and the parameters e_i, f_i, g_i, h_i are unknowns corresponding images.

2.1.2 Computation: For control points, the error equations are according to the formula (3) and (4) corresponding relative images. For Tie points, the approximations of their ground coordinates are computed based on RPC parameters and measured coordinates of stereo image pair firstly [4]. Then, their error equations are similar as control points. After the parameters e_i, f_i, g_i, h_i for each image are determined, coordinates (*s, l*) can be computed by coordinates (*c, r*) and parameters g_i, h_i. Finally, the ground coordinates (*X, Y, Z*) can be computed by RPC parameters, left image coordinates (s_l, l_l) and right image coordinates (s_r, l_r) [4].

2.2 New strict geometric model based on affine transformation

To avoid the the relativity of the traditional parameters of RSIPHR, a new, simple and strict geometric model based on affine transformation has been proposed [5]. In the new model, the strict mathematical relationship of the image coordinates (*x*, *y*) and the space coordinates (*X*, *Y*, *Z*) is

$$\frac{f - \dfrac{Z}{m\cos\alpha}}{f - xtg\alpha}\left(x - x_0\right) = a_0 + a_1 X + a_2 Y + a_3 Z \tag{5}$$
$$\left(y - y_0\right) = b_0 + b_1 X + b_2 Y + b_3 Z \tag{6}$$

2.2.1 Calculation of Parameters: Because α in the left of equation (5) is unknown, the equation is not linear. The calculation procedure is iterative based on the linearization. For simplifying, let *x* denote $x - x_0$, *y* denote $y - y_0$, in the next part of this paper. The equation (5) is linearized as following error equation:

$$da_0 + X_i da_1 + Y_i da_2 + Z_i da_3 +$$
$$x_i\left[\frac{Z_i \sin\alpha}{m(f - x_i tg\alpha)\cos^2\alpha} - \frac{x_i(f - Z_i/(m\cos\alpha))}{(f - x_i tg\alpha)^2\cos^2\alpha}\right]d\alpha +$$
$$a_0 + X_i a_1 + Y_i a_2 + Z_i a_3 - \frac{f - \dfrac{Z_i}{m\cos\alpha}}{f - xtg\alpha} = 0 \tag{7}$$

Using error equation (6) and more than 5 control points, *α*, a_0, a_1, a_2 and a_3 can be solved iteratively. From equation (6), the linear equation can be acquired:

$$b_0 + X_i b_0 + Y_i b_1 + Z_i b_2 - y_i = 0 \tag{8}$$

Using equation (8), b_0, b_1, b_2 and b_3 can be solved directly without the iteration.

2.2.2 Calculation of ground coordinates: Ground Coordinates (*X, Y, Z*) can be computed from parameters *α*, a_i, b_i, left and right image coordinates (x_l , y_l) and (x_r , y_r):

$$\begin{pmatrix} a_{l1} & a_{l2} & a_{l3} + \dfrac{x_l}{m\cos\alpha_l\left(f - x_l tg\alpha_l\right)} \\ b_{l1} & b_{l2} & b_{l2} \\ a_{r1} & a_{r2} & a_{r3} + \dfrac{x_r}{m\cos\alpha_r\left(f - x_r tg\alpha_r\right)} \\ b_{r1} & b_{r2} & b_{r3} \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \dfrac{fx_l}{f - x_l tg\alpha_l} - a_{l0} \\ y_l - b_{l0} \\ \dfrac{fx_r}{f - x_r tg\alpha_r} - a_{r0} \\ y_r - b_{r0} \end{pmatrix} \tag{9}$$

Or denote equation (9) as *AX=L***,** and then the resolution is $X=(A^TA)^{-1}A^TL$.

3. IMAGE MATCHING WITH 2D RELAXATION FOR DEM GENERATION

2 D relaxation matching should be used because there is quite large y-parallax in the approximate epipolar image pair[1] of some of the RSIPHR. Instead of grid point sampling, well-distributed feature point sampling is used in the matching approach. To ensure the reliability of the matching results, as well as fast processing, image pyramids are incorporated into the matching strategy. An algorithm for image matching, which has the ability to bridge over the poor texture areas and preserve the terrain features at high accuracy, is developed. Finally, a

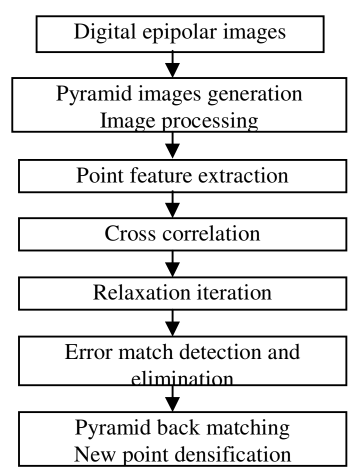


Figure 1: Workflow of matching

detection of error match and elimination function is developed. Figure 1 shows the workflow of matching approach.

3.1 Feature points extraction

In DEM generation, either predefined points (e.g. distinct points) or freely defined points must be measured. A requirement for optimality is the selection of points, which represent well the surface to be measured. The best case is to measure just these points that are sufficient to describe the surface. Therefore, feature points are extracted with location operator (Figure. 2). To ensure the well contribution of feature points, before feature point extraction, the image is divided into regular grid. Within each grid window only the feature with the best interest values is kept. The computed attributes of each feature depend on the dimensionality and on the desired computational complexity. The selected grid size depends on the image type and desired dense of match result.

3.2 Approximate value estimation

In matching, good approximations are necessary to reduce the search scale, thus reduce the number of false matches and multiple solutions. To get good approximations, two strategies have been used, image pyramid and seed point.

3.2.1 Image pyramid: Before matching, images of different levels of resolution (named image pyramid) are constructed by reducing the resolution. Instead of using a pre-defined value, the number of pyramid levels is adaptively determined according to the type of images and relative registration results. The match is firstly applied in the highest level of the pyramid. In the following pyramid level, the initial approximation is derived using match results of previous level.

3.2.2 Neighbouring and seed points: Besides image pyramid, derivation of approximate values can be achieved by using neighbouring points. The known points are relative registration results Then points close to the known ones can get approximations from their known neighbours and matching results of these points can be used to approximate other points.

3.3 Matching with 2-D relaxation

The important aspect of the relaxation match algorithm, which distinguishes it from the single point matching, is its compatible coefficient function and its smoothness constraint satisfaction scheme[2][3]. For each feature point in the left epipolar image, a search window, which centre line is alone the corresponding approximate epipolar line and its height is larger than one of the template centring in the given point, can be determined using the approximate value estimation method described above. There could be several candidate matches appearing in the search window. They can be searched by traditional cross-correlation technique in two directions (horizontal and vertical) instead of only in horizontal direction of 1-D relaxation. The candidate matches are selected if their correlation coefficient lies above a certain user-defined threshold. Let I_i be one of the feature points on the template image and I_j $(j=1,\ldots,m)$ its candidate matches on the search image. $P(i,j)$ is the probability of match $I_i \leftrightarrow I_j$. Moreover, let I_k be one of the points located in the neighbourhood of point I_i and I_l $(l=1,\ldots,m)$ are corresponding candidate matches of I_k. In order to link the matching results of the neighbouring feature points to each other, the following compatible coefficient function $C(i,j;k,l)$, which quantifies the compatibility between the match $I_i \leftrightarrow I_j$ and a neighbouring match $I_k \leftrightarrow I_l$, is defined as

$$C(i,j;k,l) = \frac{T}{\exp[(\Delta p_x^{\ 2} + \Delta p_y^{\ 2})/\beta]} \tag{10}$$

$$\Delta p_x = (x_j - x_i) - (x_l - x_k)$$

$$\Delta p_y = (y_j - y_i) - (y_l - y_k)$$

In equation (10), Δp_x expresses the difference of the x-parallaxes in point I_i and its neighbouring point I_k, while Δp_y the difference of the y-parallaxes. The bigger the Δp is, the smaller the compatibility. This corresponds to a smoothness constraint on the image matching results, and it provides an ability to bridge over the poor texture areas by assuming the parallax surface varies smoothly. T and β are constant values. In the relaxation scheme, the global consistency of matching can be achieved by an iterative scheme where the probabilities $P(i, j)$ are updated by the following rule:

$$p^{(n+1)}(i,j) = \frac{p^{(n)}(i,j)Q^{(n)}(i,j)}{\sum_{s=1}^{m} p^{(n)}(i,s)Q^{(n)}(i,s)}$$

$$Q^{(n)}(i,j) = \prod_{I_k \in \Omega(I_i)} \sum_{l=1}^{m} p^{(n)}(k,l)C(i,j;k,l)$$

$\Omega(I_i)$ is the neighbourhood of point Ii (can be determined by TIN construction or neighbourhood relation), and n is the iteration number. The quantity $Q^{(n)}(i, j)$ expresses the support of the match $I_k \leftrightarrow I_l$ received at the nth iteration from the matches $I_k \leftrightarrow I_l$ in its neighbourhood $\Omega(I_i)$. The iteration scheme can be initialised by assigning the normalized correlation coefficient to $P^{(0)}(i, j)$ and, ideally the process will terminate when an unambiguous match result is reached, that is when each point I_i is matched with one candidate with probability 1, the probabilities for all other candidate matches for this point being zero. In practice the process is terminated if any one of the following 2 conditions holds: a. For each feature point I_i, one of the match probabilities $P(i,j)$ $(j=1,\ldots,m)$ exceeds 1-ε, where ε<<1. b. Pre-defined number of iterations has been reached. The match, which gains the highest probability $P(i, j)$ $(j=1,\ldots,m)$, is selected as the actual conjugate. By the refinement of relaxation technique, the feature point based matching method becomes more reliable and robust.

3.4 Check and filter

Even though the matching approach made full use of the advantages feature point sampling and useful refinement based on probability relaxation, we can't guarantee that the all match results are completely correct. In addition, the errors produced at the lower pyramid level often greatly influence the result at subsequent level. So a system of checking and eliminating blunders and false matches appears very important.

So an error detection function has been developed, witch considers the smoothness constraint satisfaction scheme. For each match, a weighted mean approximation can be calculated with neighbouring points. If the difference between the match and the approximation exceeds a predefined threshold, we deem it is a false match and delete it. The weight is distance dependent. The more distant is, the less the weight. The results show that this checking method can efficiently detect and eliminate most blunders and false match.

4. FAST AND ACCURATE RECTIFICATION OF RSIHR

After acquiring the image parameters and DEM, the RSIHR can be rectified to orth-image, which is geo-referenced and is the base of quantificational processing and analysis. The common method of the rectification is indirect algorithm as following.

4.1 Computation of ground coordinates

If the coordinates of a point *P* on orthoimage are (X', Y'), Its plane coordinates on the ground can be calculated by the coordinates (X_0, Y_0) of the down-left corner and the scale *M* of orthoimage:

$$X = X_0 + M X'$$
$$Y = Y_0 + M Y' \qquad (11)$$

4.2 Computation of image coordinates

The height of point *P* is interpolated based on DEM and (X, Y). Then the image coordinates of the point *P* can be computed by the ground coordinates (X, Y, Z) and image parameters.

4.3 Interpolation of gray level

Because the image point is usually not in the center of a pixel, the gray level $g(x, y)$ should be interpolated by bilinear polynomials.

4.4 Gray level mapping

Final, the gray level $g(x, y)$ by the interpolation will be put to the pixel of orthoimage:

$$G(X, Y) = g(x, y) \qquad (12)$$

In order to accelerate the rectification, the rectified unit is a facet instead of pixel by pixel in fact. Only the image coordinates (x_1, y_1) (x_2, y_2) (x_3, y_3) (x_4, y_4) of the four corners in each grid of the DEM are computed by image parameters and ground coordinates, and the image coordinates $x(i,j)$ and $y(i,j)$ of the points within the grid are interpolated by bilinear polynomials respectively.

$$x(i,j) = \frac{1}{n^2}[(n-i)(n-j)x_1 + i(n-j)x_2 + (n-i)jx_4 + ijx_3]$$
$$y(i,j) = \frac{1}{n^2}[(n-i)(n-j)y_1 + i(n-j)y_2 + (n-i)jy_4 + ijy_3] \qquad (13)$$

Where n is the number of rows and columns in the window corresponded to the DEM grid, and i, j are the number of row and column of the pixel.

5. RESULTS OF EXPERIMENTS

Table 1 shows the accuracy of parameter computation in 14 cases for one IKONOS image pair. There are 25 known points in the pair. Case 0 is using only RPC parameters, and cases 1.1 to 1.6 are applying the block adjustment based on RPC parameters, selecting 1, 2, 3, 4, 5 and all of the 25 points as control points respectively. Case 2.1 to 2.5 are utilizing the strict geometric model based on affine transformation with 25, 18, 12, 8 and 6 control points respectively. Case 3.1 is the RMSE from measured and known coordinates of 77 feature points, and case 3.2 is height RMSE of 95 points in DTM. Table 2 shows the accuracy of parameter computation in a block with 14 IKONOS images, which are from 3 orbits and generate 9 modelswith 9 known points. Table 3 shows the accuracy of parameter computation for SPOT images, which parts are shown in figure 2. Figure 2 shows the matching results of a SPOT image pair by the method presented above. Figure 3(a) shows the orthoimage correspounding with the image in Figure 2 by the method discribed above. Figure 3(b) is the orthoimage from IKONOS image.

Tab.1 Parameter calculation of IKONOS stereo image pair

case	Control points(m)				Check points(m)			
	N	Mx	My	Mz	N	Mx	My	Mz
0	0				13	3.055	3.155	16.085
1.1	1	0.000	0.000	0.000	24	0.567	1.478	1.581
1.2	2	0.190	0.598	0.232	23	0.609	0.580	1.522
1.3	3	0.016	0.317	0.001	22	0.774	0.548	0.967
1.4	4	0.179	0.561	0.097	21	0.583	0.674	1.006
1.5	5	0.425	0.540	0.571	20	0.614	0.575	0.973
1.6	25	0.532	0.527	0.901	0			
2.1	25	0.031	0.028	0.088	0			
2.2	18	0.030	0.029	0.094	0	0.044	0.031	0.082
2.3	12	0.030	0.030	0.081	0	0.037	0.028	0.096
2.4	8	0.022	0.034	0.084	0	0.044	0.028	0.107
2.5	6	0.024	0.012	0.034	0	0.042	0.037	0.125
3.1	25	0.031	0.028	0.088	77	1.098	0.774	0.852
3.2	25	0.031	0.028	0.088	95			1.30

Tab.2 Parameter calculation of IKONOS image block

case	Control points(m)				Check points(m)			
	N	Mx	My	Mz	N	Mx	My	Mz
4.1	1	0.118	0.109	0.191	8	1.477	1.132	0.927
4.2	2	0.125	0.146	0.215	7	0.631	0.578	0.883
4.3	3	0.395	0.115	0.396	6	0.609	0.849	0.866
4.4	5	0.481	0.107	0.521	4	0.484	0.522	0.592
4.5	9	0.521	0.315	0.436	0			

Tab. 3 Parameter calculation of SPOT image

Control points(m)				Check points(m)			
N	*Mx*	*My*	*Mz*	N	*Mx*	*M*	*Mz*
67	9.401	11.745	5.311	11	7.745	15.282	4.753
49	9.537	10.898	5.378	29	11.242	15.397	6.374
30	9.456	10.148	4.172	48	10.553	13.853	7.111
10	3.487	5.856	3.989	68	11.749	15.553	6.072

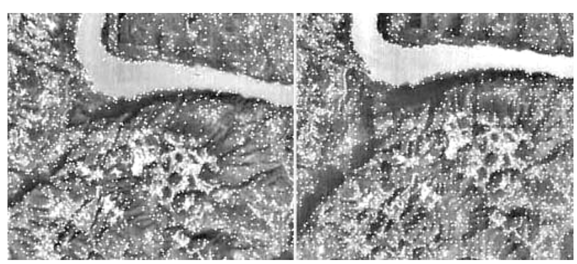
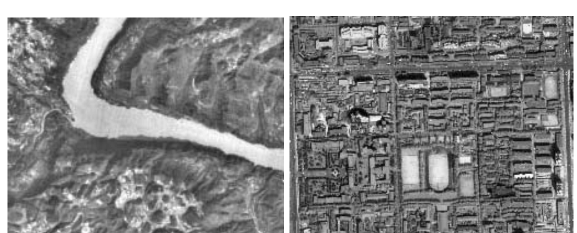


Fig. 2 Result of automatic matching of SPOT image pair



6. CONCLUSION

The key technique producing orthpoimage from RSIHR includes the parameter computation of RSIHR, image matching to creating DTM and fast orthogonal rectification of RSIHR.The parameter computation of RSIHR can be based on two ways. One is the block adjustment with RPC/RPB parameters for IKONOS and QUICKBIRD images, which needs less control points. The other is the new strict geometric model based on affine transformation for any RSIPHR, which needs more than five control points per image. The accuracy of both methods can reach to the level corresponding to the ground resolution of the image.Quite large y-parallax is remained in the approximate epipolar image pair of some RSIHR after relative registration. 2-D relaxation matching, based on feature points, can overcome the disadvantage in the DTM Modelling from RSIHR.

The block adjustment of the new strict geometric model based on affine transformation for any RSIPHR is the farther research work to reduce the number of control points.

Acknowledgements

Thanks for the supporting from Natural Science Fund of P. R. China (No. 40171081). Thanks Gene Dial of SPACEIMAGE for supporting the IKONOS data and materials.

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