# BLOCK ADJUSTMENT BASED ON NEW STRICT GEOMETRIC MODEL OF SATELLITE IMAGES WITH HIGH RESOLUTION

Jianqing Zhang*, Yong Zhang, Ying Cheng

School of Remote Sensing and Information Engineering, Wuhan University, Wuhan, China, 430079 - (jqzhang,yongzhang)@supresoft.com.cn, cheng99ying@163.com

**Commission VI, WG III/1**

**KEY WORDS:** Remote Sensing, Photogrammetry, High resolution, Block, Adjustment, Transformation, Exterior, Parameters

**ABSTRACT:**

The satellite image with high resolution has been commercially available since early 21st century, and the generation of digital elevation model and Ortho-image with lower costs and shorter period from these high-resolution images has become practical. But at first one must calculate the parameters of these high-resolution images. Recently, A new strict geometric model, based on affine transformation, for RSIHR was proposed. In the new model, there are eight affine coefficients and one slantwise angle for each image. However, in order to calculate the nine parameters, more than five control points are needed. Therefore, many control points should be used in a block for the new model. It is difficult to acquire many control points in a block, and block adjustment with the new model based few control points is necessary for computing the parameters of every image in the block. After the new strict geometric model, based on affine transformation, for RSIHR is briefly presented, the method of the block adjustment with the new model is introduced in this paper. At last, the method of the block adjustment with the new model has been tested for IKONOS and other HRSI. The block adjustment based on RPC parameters with IKONOS images has been tested also and compared with the new strict geometric model. All the tested result shows that the accuracy of the new model can reach the level corresponding to the ground resolution of the images.

## 1. INTRODUCTION

High-resolution satellite imagery (HRSI) has been commercially available since early 21$^{st}$ century, and the generation of digital elevation model and Ortho-image with lower costs and short period from these HRSI has become practical. But at first one must calculate the parameters of these high-resolution images.

High-resolution satellite images are acquired with Linear Array Push-Broom Scanners. Because of the strong relativity of the traditional parameters of remote sensing imagery, these parameters could not be acquired sometimes. So it is necessary to find some new way for sensor orientation for high-resolution satellite imagery.

Recently, The Rational Polynomial camera (RPC) model has consequently gained a considerable degree of popularity for 3D object feature positioning from HRSI, especially given that they have been shown to yield accuracies commensurate with rigorous photogrammetric models (Grodecki, 2001). For example, IKONOS and QUICKBIRD imagery have RPC or RPB parameters that provided by the image suppliers. But RPC/RPB parameters could not be used for directly geo-positioning, block adjustment with control points is necessary. It has recently been demonstrated that a bundle adjustment approach can be employed with IKONOS imagery to yield bias-corrected RPCs that enable sub-pixel geo-positioning and, subsequently, high-accuracy DTM extraction and ortho-image generation (e.g. Fraser and Hanley, 2003; Godecki and Dial, 2003; Jianqing Zhang and Shunyi Zheng, 2003).

But unfortunately, not all high-resolution satellite images are supported by RPC or RPB parameters. Therefore, a new strict geometric model, based on affine transformation, for the high-resolution images without RPC or RPB parameters, was proposed (Jianqing Zhang and Zuxun Zhang, 2002). In this new model, there are eight affine coefficients and one slantwise angle for each image. Recent research has revealed this new model has yielded geo-positioning accuracy no less than that obtained via bias-corrected RPC block adjustment (Jianqing Zhang and Shunyi Zheng, 2003). However in order to calculate the nine parameters, more than five control points are needed. Therefore, many control points should be used in a block. It is difficult to acquire many control points in a block, and block adjustment with the new model based few control points is necessary for computing the parameters of every image in the block.

In this paper, we will concentrate upon the approach of block adjustment based on the new model with few control points. In section 2, the method of block adjustment based on the new model is introduced. The calculation of the initial value of terrain coordinates of the tie points and orientation parameters (eight affine coefficients and one slantwise angle) of each image will be discussed in section 3. At last, the method of block adjustment with the new model has been tested for IKONOS images and other HRSI respectively. The block adjustment based on RPC parameters with IKONOS images has been tested also and compared with the new model. All test results shows that accuracy of the new model can reach the level corresponding to the ground resolution of the images.

* Corresponding author.

## 2. BLOCK ADJUSTMENT BASED ON THE NEW STRICT GEOMETRIC MODEL

Jianqing Zhang and Zuxun Zhang (2002) have proposed a three-step image orientation model for HRSI based on parallel projection. In this new strict geometric model, a similarity transformation is first employed to reduce 3D object space to 2D image space, which is then projected to a level plane via affine projection, and finally the level image is transformed to the actual inclined image. The equation between the image coordinates of the point and the terrain coordinates of the points is described as the below:

$$\frac{f-\dfrac{Z}{m\cos\alpha}}{f-(x-x_0)\tan\alpha}(x-x_0)=a_0+a_1X+a_2Y+a_3Z \qquad (1)$$
$$y-y_0=b_0+b_1X+b_2Y+b_3Z$$

For the purpose of simplification, in the below, $x-x_0$ and $y-y_0$ will be substituted by $x$ and $y$ respectively.

This model comprises eight affine transformation parameters and one slantwise angle. The influence of the slantwise angle can be derived as the below (Fraser, 2003):

$$\Delta x\approx-\frac{\Delta Z}{f\cos\alpha}x \qquad (2)$$

where $\Delta Z$ is the terrain height variation. For IKONOS imagery, Fraser pointed out that the influence of the slantwise angle in equation (1) could be ignored when the height variations in the image is less than or about 500m. But this conclusion is not always the truth for other satellite imagery with high resolution. In the second test case of this paper, the calculated values of the slantwise angles of the satellite images are about 7~8 degree and the correction of $x$ coordinates can reach to 9.4 pixels for $\Delta Z=300$ meter.

If the orientation parameters of the images are all known, the terrain coordinates of the tie point in the block can be calculated As follows:

$$(A^TPA)\cdot X=A^TPL \qquad (3)$$

where:

$$A=\begin{bmatrix} a_{i1} & a_{i2} & a_{i3}+\dfrac{x_i}{m\cos\alpha_i(f-x_i\tan\alpha_i)} \\ b_{i1} & b_{i2} & b_{i3} \\ a_{j1} & a_{j2} & a_{j3}+\dfrac{x_j}{m\cos\alpha_j(f-x_j\tan\alpha_j)} \\ b_{j1} & b_{j2} & b_{j3} \\ \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3}+\dfrac{x_n}{m\cos\alpha_n(f-x_n\tan\alpha_n)} \\ b_{n1} & b_{n2} & b_{n3} \end{bmatrix},\quad L=\begin{bmatrix} \dfrac{fx_i}{f-x_i\tan\alpha_i}-a_{i0} \\ y_i-b_{i0} \\ \dfrac{fx_j}{f-x_j\tan\alpha_j}-a_{j0} \\ y_j-b_{j0} \\ \cdots \\ \dfrac{fx_n}{f-x_n\tan\alpha_n}-a_{n0} \\ y_n-b_{n0} \end{bmatrix}$$

The equation (1) is linearized as following error equation:

$$\begin{aligned} v_x&=c_0da_0+c_1da_1+c_2da_2+c_3da_3+c_4d\alpha+ \\ &\quad c_5dX+c_6dY+c_7dZ-l_x \\ v_y&=d_0db_0+d_1db_1+d_2db_2+d_3db_3+ \\ &\quad d_4dX+d_5dY+d_6dZ-l_y \end{aligned} \qquad (4)$$

where:

$$\begin{aligned} l_x&=-a_0-a_1X-a_2Y-a_3Z+\frac{f-\dfrac{Z}{m\cos\alpha}}{f-x\tan\alpha}\cdot x \\ l_y&=-b_0-b_1X-b_2Y-b_3Z+y \\ c_0&=1,\ c_1=X,\ c_2=Y,\ c_3=Z \\ d_0&=1,\ d_1=X,\ d_2=Y,\ d_3=Z \\ c_4&=\frac{Zx\sin\alpha}{m(f-x\tan\alpha)\cos^2\alpha}-\frac{x^2(f-\dfrac{Z}{m\cos\alpha})}{(f-x\tan\alpha)^2\cos^2\alpha} \\ c_5&=a_1,c_6=a_2,c_7=a_3+\frac{x}{m\cos\alpha(f-x\tan\alpha)} \\ d_4&=b_1,d_5=b_2,d_6=b_3 \end{aligned} \qquad (5)$$

In addition, the control points are also treated as observations with appropriate weight. Then the error equations of the block adjustment are:

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix}=\begin{pmatrix} A_1 & A_2 \\ 0 & E_2 \end{pmatrix}\cdot\begin{pmatrix} X_1 \\ X_2 \end{pmatrix}-\begin{pmatrix} L_1 \\ L_2 \end{pmatrix},\quad \begin{pmatrix} P_1 \\ P_2 \end{pmatrix} \qquad (6)$$

In equation (4), $X_1$ is the corrections vector of the orientation parameters of the images and the unknown terrain coordinates and $A_1$ is the coefficients matrix of the error equation (2). $X_2$ is the corrections vector of the terrain coordinates of the control points and $E_2$ is unit matrix.

In each iterative step, the statistical hypothesis of the significance tests for all the slantwise angles of the images is executed. Assuming $E(\alpha_i)=0$, the statistical variable of the t-distribution is obtained as follows:

$$t=\frac{|\alpha_i|}{s_0\cdot\sqrt{q_{ii}}}\sim t_\nu \qquad \nu=n-u \qquad (7)$$

where $s_0=\sqrt{\dfrac{V^TPV}{n-u}}$ is the mean square error of unit weight, obtained from adjustment computations, and its expectation is $\sigma_0\cdot$ $q_{ii}$ is taken from the corresponding diagonal element of the cofactor matrix $Q$ of the unknowns in the adjustment. When the significance level is given, then we can find the critical value $t_a$ from the t-distribution table. If $t<t_a$, then the null hypothesis is accepted, which means that the slantwise angle $\alpha_i$ is not significant and can be eliminated in the next iterative adjustment.

## 3. INITIAL VALUE OF THE BLOCK ADJUSTMENT

To start the block adjustment, at first one must calculate the initial value of the orientation parameters of every image and the terrain coordinates of the tie points in the block. From the equation (1), it need at least five control points for each high-resolution satellite image to calculate the eight affine parameters and one slantwise angle. However, it is difficult to acquire many control points in a block. Therefore, one must find some way to reduce the necessary control points for the orientation of the images.

Firstly, when calculating the initial value of the orientation parameters of the image, one can suppose that the slantwise angle is zero approximately. Therefore, only four control points is necessary for each image to calculate the initial value of the orientation parameters.

Secondly, the control points can be set in the overlap zone of the adjacent models in order to reduce the necessary control points. In Figure 1, the control point 3 and 4 are the mutual control points of the adjacent models. Then only six control points are necessary for the initial orientation of the two models.

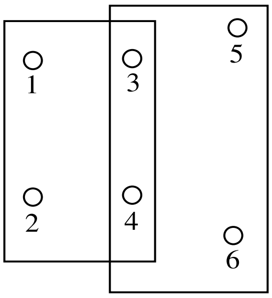


Figure 1: Distribution of control points

Thirdly, a block usually is composed of many images in several orbits. The test block shown in Figure 2 is composed of 15 images in three orbits. In each orbit, one can combined the images into two images to form a bigger model. For example, as shown in Figure 2, there are fifteen images in the block. In order to calculate the initial values:

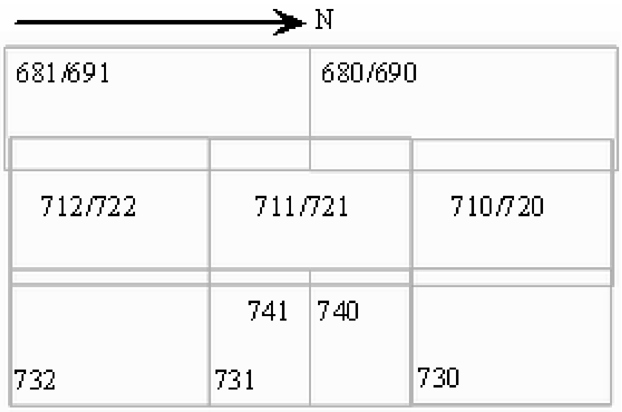


Figure 2: Test Block with 15 IKONOS images in three orbits

In the first orbit, the image 681 and 680 can be combined into one big image and the image 691 and 690 can be combined into another big image.

In the second orbit, 712, 711 and 710 can be combined into one big image and 722, 721 and 720 can be combined into another image.

In the third orbit, the image group (732~730) and image group (740, 741) can be combined into two big images respectively.

Then for each orbit, only four control points are necessary for the orientation of the combined bigger images. If we set four control points in the overlap zone of the adjacent orbits, then only eight control points are necessary for the block.

After the orientation of these six combined images, the initial value of the terrain coordinates of all tie points can be calculated by equation (3).

From the above discussion, the initial orientation parameters of the HRSI in the block can be calculated in the below step:

1. For each orbit, combine the images in the orbit into a bigger stereo model and use four control points to calculate the orientation parameters (not include the slantwise angles) of the two bigger combined images.
2. Use the orientation parameters of the bigger combined images in each orbit to calculate the initial value of the terrain coordinates of the tie points in the block.
3. Use the initial value of the terrain coordinates of all tie points to calculate the orientation parameters of each actual image in the block.

## 4. TEST RESULTS OF THE BLOCK ADJUSTMENT

### 4.1 TEST RESULTS OF IKONOS BLOCK

The first test block has 15 IKONOS images in three orbits. The photograph area is about 1995 $km^2$ (35*57 km). The block has 86 GCPs in all. The location of the GCPs within the test block is shown in Figure 3. All the GCPs are in the UTM coordinate systems. The terrain height variation is about 600 meter in the block.

The block adjustment based on the new strict geometric model has been tested for all the 86 GCPs, 20 GCPs and 8 GCPs three cases respectively. The test results are listed in the Table 1. The results of the block adjustment based on RPC model (the forth cases in the Table 1) are also listed for the purpose of comparison.

Table 1: The block adjustment results of the IKONOS imagery

| $\sigma_0$ (Pixel) | Control points (m) | | | | Check points (m) | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Mx | My | Mz | N | Mx | My | Mz |
| 0.32 | 86 | 0.37 | 0.44 | 0.74 | | | | |
| 0.31 | 20 | 0.21 | 0.33 | 0.62 | 66 | 0.59 | 0.58 | 0.87 |
| 0.32 | 8 | 0.19 | 0.20 | 0.56 | 78 | 0.56 | 0.72 | 1.15 |
| 0.35 | 5 | 0.39 | 0.32 | 0.40 | 81 | 0.87 | 0.85 | 0.93 |

From the adjustment results listed in the Table 1, one can draw the conclusion:

1. The accuracy of the block adjustment with strict geometric model can reach to the level corresponding to the ground resolution of the image and the accuracy can be improved by increasing the number of the control points.
2. The planimetric accuracy of the block adjustment with strict geometric model is better than the accuracy of the adjustment based on RPC model.

3. The height accuracy of the block adjustment with strict geometric model is coequal to the accuracy of the block adjustment based on RPC model.

### 4.2 TEST RESULTS OF BLOCK WITH OTHER HRSI

The second test block has six HRSI images in one orbit. The pixel size of these images is three meter and the photograph area is about 2700 $km^2$ (90*30 km). As shown in the Figure 4, there are 39 GCPs in the block. All the GCPs are in the UTM coordinate systems. The terrain height variation is about 300 meter in the block.

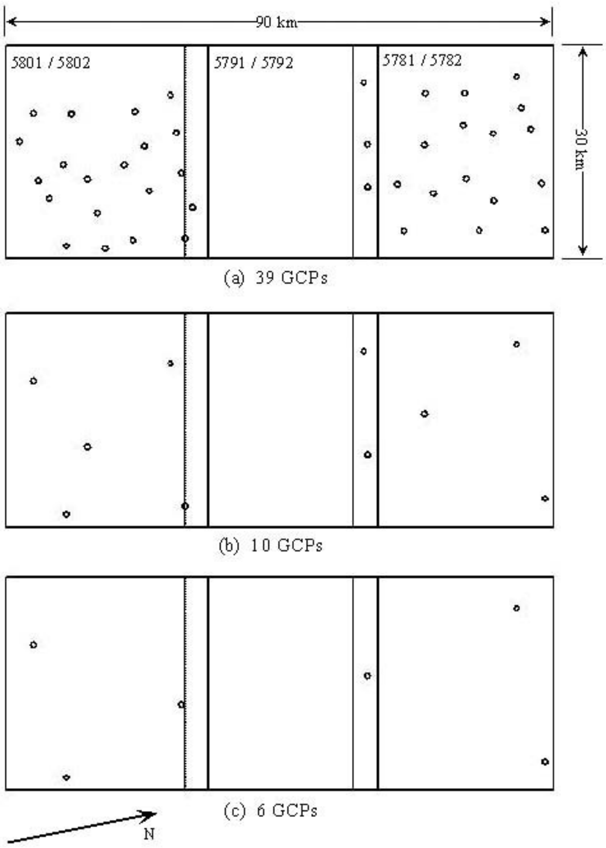


Figure 4: The location of GCPs with the third test block. The block has 6 images in two orbits. There are 39 GCPs in all. The block adjustment has been tested for all the 39

The block adjustment has been tested for all the 39 GCPs, 10 GCPs and 6 GCPs three cases respectively and the test results are listed in the Table 2. From the result we can see that the planimetric accuracy of the block adjustment reach the level corresponding to the ground resolution of the image. But the accuracy of the height is a bit worse. One of the reason is the image is not very clear (Figure 5). The other reason is the poor location of the GCPs: there are no GCP in the center of the block while the span of the block is 90 km.

Table 2: The block adjustment results of the CBS-2 imagery

| $\sigma_0$ Pixel | Control points (m) | | | | Check points (m) | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Mx | My | Mz | N | Mx | My | Mz |
| 0.24 | 39 | 3.14 | 2.28 | 6.74 | | | | |
| 0.22 | 10 | 1.46 | 0.88 | 4.22 | 29 | 3.79 | 2.93 | 7.04 |
| 0.23 | 6 | 1.48 | 1.09 | 2.61 | 33 | 5.98 | 3.79 | 6.44 |

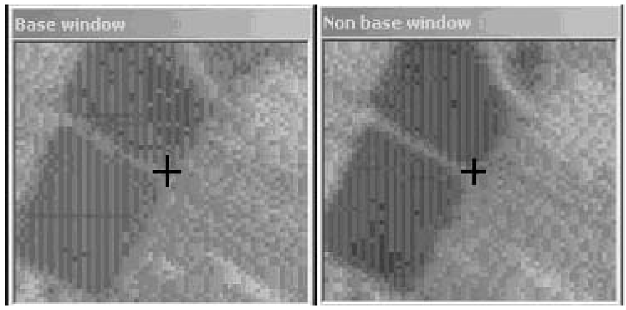


Figure 5: The image windows (zoom ratio is 3) in the second test block.

Table 3 shows the block adjustment results of the single models (model 5781/5782 and 5801/5802) in the third block. In each model, all the control points are used to calculate the orientation parameters.

Table 3: The block adjustment results of the single model in the third test block

| Model | Control points (m) | | | |
|---|---|---|---|---|
| | N | Mx | My | Mz |
| 5781/5782 | 19 | 5.57 | 2.19 | 4.19 |
| 5801/5802 | 20 | 4.87 | 2.34 | 7.92 |

Compared to the results shown in Table 2, we can see that the accuracy of the block adjustment with multi models reach the same level of the accuracy of the single model.

## 5. CONCLUSION

In this paper, a new approach of the block adjustment based on the new strict geometric model for HRSI is introduced. In order to reduce the number of necessary control points for the calculation of the initial value of the block adjustment, a procedure with three steps is proposed. The new approach of the block adjustment has been tested for IKONOS and CBS-2 images respectively. All the test results show that the accuracy of the block adjustment can reach to the level corresponding to the ground resolution of the image.

Compared with the block adjustment based on RPC model, though the block adjustment based on RPC model may need fewer control points, this new approach has larger potential in the application of HRSI because most of high-resolution satellite imagery has no RPC parameters supported.

**Acknowledgements**

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

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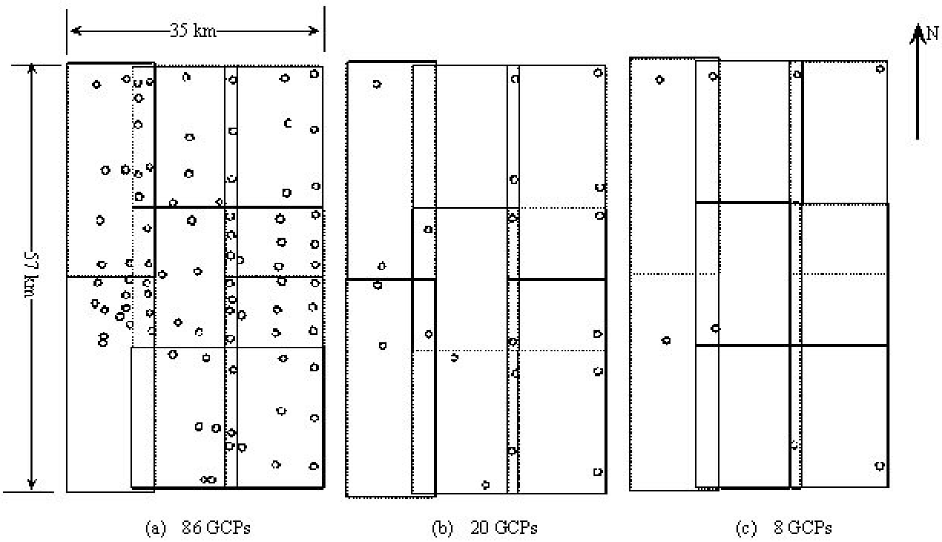


Figure 3: The location of GCPs with the first test block. The block has 15 IKONOS images in three orbits. There are 86 GCPs in all. The block adjustment has been tested for all the 86 GCPs, 20 GCPs and 8 GCPs three cases respectively.