CAMERA STATION BASED **COMBINER ADJUSTMENT OF MULTI-IMAGES**

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ABSTRACT:

Orientation and rectification of remote sensing imagery is one of the most important tasks for imagery processing, remote sensing imagery data transformed to specific coordinate system and with coordinate information is not only the directly requirement of surveying, but also the basic of image deeper processing. At the condition of without GCP (ground control point), the ground orientation accuracy of remote sensing imagery principally depends on the accuracy of elements of exterior orientation. Till now, some remote sensing satellite has no mounted high-accuracy attitude surveying equipment such as star tracker or gyrostat, but satellite–carried GPS receivers are applied more and more extensivly，the accuracy of orbit surveying improves constantly, which can even reach meter sized. On the premise that satellite orbit has high accuracy, the primary reason influencing orientation accuracy is satellite attitude angle. Combined adjustment of multi-image is a method to reach the result of improving the orientation accuracy of image, which is said that corresponding control (connection) points is used for basic constrained condition, use position-exterior elements of corresponding images for given values, to improve attitude angles accuracy of all the images. This paper use collinear equations for foundation, detailed elaborates on mathematics modeling, deduces and solves of errors equations. We use three views of neighbor frame images of a recoverable scientific experiment satellite for experiment data, the result indicated that the ground orientation accuracy of the other two pieces of images without ground control can be increase from kilometer sized to the level of tens-meters, so, it is a effective method which uses surveying adjustment technique to improve rectification and orientation accuracy of remote sensing imagery that without or less GCPs

1. INTRODUCTION

1.1 General Instructions

Orientation of remote sensing imagery from space is the basic content of remote sensing imagery application. The orientation accuracy of remote sensing imagery mainly rest with the accuracy of exterior orientation parameters at the time of image shooting. The satellite image has terrible orientation accuracy from space under the condition of no ground control point (GCP) due to some remote sensing satellite has no mounted high-accuracy attitude surveying equipment such as star tracker or gyrostat. But the accuracy of satellite orbit measurement can reach higher easily with the development of satellite orbit orientation technique and more and more extensive application of GPS for the field of satellite orbit orientation. The primary reason for orientation accuracy from space is the accuracy of angle elements at the time of satellite shooting under the condition of higher orbit orientation accuracy. The lower error of satellite position is represented as the same translation for influence of pixels orientation errors and has a little influence for interior geometric relation of rectified image. In order to carry out higher orientation accuracy of lager area with little GCPs, this paper will make the orbit observation values of satellite shooting for known terms, correct exterior orientation attitude angle elements of each image using the connecting points on overlapping part between images shot at different positions, and correct satellite orbit position error effecting image orientation with attitude angles to improve the accuracy of image orientation from space.

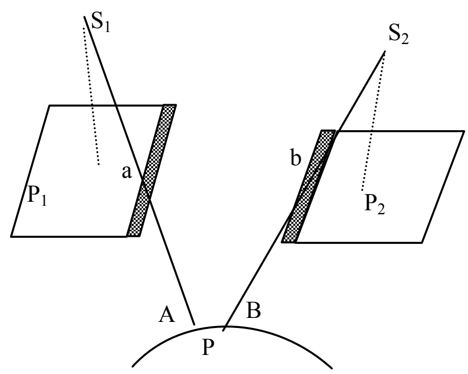

Figure 1: Sketch map of connecting

As shown in figure (1), P_1 and P_2 are two overlapped images, and the shadow is overlapping area because of different shooting positions. Pixels a and b are the same target point P that respectively lies on P_1 and P_2, which are seen as connecting points. S_1 and S_2 are camera station positions of two images for the same place. S_1a and S_2b intersect at the same point P at the perfect condition. a and b are projected on A and B respectively when observation values of photogrammetry exist errors. In this paper, a and b are projected on P accurately by correcting attitude angle value of image when S_1 and S_2 keep immovable.

2. ADJUSTMENT MODEL

2.1 Collinear equation for image under geocentric coordinate system

2.1.1 Look direction of pixel in sensor coordinate system

Sensor coordinate system use the center of lens as origin, Y axis points to flight direction, X axis points to right side of flight direction, and Z axis point to ground, which compose right handed system. The pixel coordinate in sensor coordinate system is [x' y' z']. The look direction vector composed with projection center at the time of imaging is $\vec{u}_s^{'}$, as followed:

$$\vec{u}_s^{'} = \begin{bmatrix} x-x_0 & y-y_0 & -f \end{bmatrix}^T = [x' \quad y' \quad z'] \qquad (1)$$

Where (x_0, y_0) is the coordinate of coordinate of principal point. So in sensor coordinate system, the unit vector of line-of slight is :

$$\vec{u}_s = \frac{\vec{u}_s^{'}}{\left\| \vec{u}_s^{'} \right\|} \qquad (2)$$

2.1.2 Look direction of pixel in body coordinate system

Coordinate origin locates at centroid of satellite, X-axis, Y-axis and Z-axis are determined as three main axes of inertia for satellite individually, where X-axis is along horizontal axis of satellite, and Y-axis is along vertical axis which points to flight direction of satellite. Three axes in sensor coordinate system usually parallel to these in body coordinate system, but there will be a designed value according to requirement. Meanwhile, there is fixed error when sensor is fixed on body in term of designed value. Three orthographic angles ey, ex, ez are always made for transforming body coordinate system to sensor coordinate system. So RSC which is the transform from sensor coordinate system to body coordinate system as followed:

$$R_S{}^C = \mathrm{Re_x Re_y Re_z} \qquad (3)$$

2.1.3 Look direction of pixel in orbit coordinate system

The coordinate origin of orbit coordinate system is at the instantaneous shot position of satellite, which uses the direction from geocenter to satellite for Z-axis, and direction of velocity for Y-axis, sets up orbit coordinate system according to right handed system. Nowadays, most high resolution remote sensing satellites are added drift angle to eliminate the influence of image distortion from rotation of the Earth. Therefore, under this condition, look direction can be transformed from noumenon coordinate system to orbit coordinate system by rotation of three attitude angles ω , φ , κ , the related transformation matrix R_CO can be shown as:

$$R_C{}^O = R_p \bullet R_r \bullet R_y \qquad (4)$$

2.1.4 Look direction of pixel in earth-fixed geocentric coordinate system

The location and velocity individually are $\vec{P}(t)$ and $\vec{V}(t)$ in earth-fixed coordinate system, which are obtained from interpolation from ephemeris of satellite, and defined in term of orbit coordinate system, the equations expressed below:

$$\vec{Z}_o = \frac{\vec{P}(t)}{\left\|\vec{P}(t)\right\|}, \quad \vec{X}_o = \frac{\vec{V}(t)\Lambda\vec{Z}_o}{\|\vec{V}(t)\Lambda\vec{Z}_o\|}, \quad \vec{Y}_o = \vec{Z}_o\Lambda\vec{X}_o$$

The transformation matrix ROE from orbit coordinate system to earth-fixed geocentric coordinate system can be obtained from look direction:

$$R_O{}^E = \begin{bmatrix} (X_o)_X & (Y_o)_X & (Z_o)_X \\ (X_o)_Y & (Y_o)_Y & (Z_o)_Y \\ (X_o)_Z & (Y_o)_Z & (Z_o)_Z \end{bmatrix} \qquad (5)$$

2.1.4 Computation of projection center position in geocentric coordinate system

For surveying satellite, adjustment of attitude angles usually are achieved by satellite movement in order to keep stability of satellite sensor at the time of image acquisition. The recorded data is the location of GRS antenna when there is GPS receiver on satellite. But the locations of GPS antenna and projected center of sensor do not lie on the same point on satellite, so this error should be spread to orientation of image from space under the condition of no GCPs. This can be eliminated by calculating when the requirement of model is rigorous. In the body coordinate system of satellite, the vector of projected center location for sensor relative to satellite-borne GPS antenna which is obtained by testing and detecting is [X_{GPS_CAM}, Y_{GPS_CAM}, Z_{GPS_CAM}], so the relationship of projected center coordinate [Xs Ys Zs] and the coordinate [X_{GPS} Y_{GPS} Z_{GPS}] calculated from GPS receiver in earth-fixed geocentric coordinate system is:

$$\begin{bmatrix} Xs \\ Ys \\ Zs \end{bmatrix} = \begin{bmatrix} X_{GPS} \\ Y_{GPS} \\ Z_{GPS} \end{bmatrix} + \mathrm{R_O{}^E R_C{}^O} \begin{bmatrix} X_{GPS\_CAM} \\ Y_{GPS\_CAM} \\ Z_{GPS\_CAM} \end{bmatrix} \qquad (6)$$

2.1.5 Collinear equation under geocentric coordinate system

Direction vector of pixel Look direction in earth-fixed geocentric coordinate system can be obtained by above transformation as followed:

$$\vec{u}_E^{'} = \mathrm{R_O{}^E \bullet R_C{}^O \bullet R_S{}^C} \bullet \vec{u}_s \qquad (7)$$

And in geocentric coordinate system, the direction vector from point on the ground to position of the satellite is the difference of geocentric coordinate between two points:

$$\vec{u} = \begin{bmatrix} X - Xs \\ Y - Ys \\ Z - Zs \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} - \begin{bmatrix} Xs \\ Ys \\ Zs \end{bmatrix} \qquad (8)$$

where $[X\ Y\ Z]^T$ is the ground point coordinate in geocentric coordinate system, $[Xs\ Ys\ Zs]^T$ is the position of satellite in geocentric coordinate system.

Obviously, direction of vector $\vec{u}_E'$ is same as vector $\vec{u}$, and for their modules, only one scale constant λ is need to multiply: $\vec{u} = \lambda\ \vec{u}_3'$, combined with equation (5):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} - \begin{bmatrix} X_{GPS} \\ Y_{GPS} \\ Z_{GPS} \end{bmatrix} - R_O^E R_C^O \begin{bmatrix} X_{GPS\_CAM} \\ Y_{GPS\_CAM} \\ Z_{GPS\_CAM} \end{bmatrix} = \lambda R_O^E \bullet R_C^O \bullet R_S^C \begin{bmatrix} x - x_0 \\ y - y_0 \\ -f \end{bmatrix} \quad (9)$$

So this is the direct 3D linear transformation equation between image space coordinate (x y -f) and object space coordinate (X Y Z) in geocentric system. If

$$M = R_O^E \bullet R_C^O \bullet R_S^C = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{31} & m_{33} \end{bmatrix}$$

For arbitrary ground point coordinate (X_j Y_j Z_j), can be expressed as:

$$\begin{cases} X_j = Xs_j + \dfrac{m_{11}x + m_{12}y - m_{13}f}{m_{31}x + m_{32}y - m_{33}f}(Z_j - Zs_j) \\ Y_j = Ys_j + \dfrac{m_{21}x + m_{22}y - m_{23}f}{m_{31}x + m_{32}y - m_{33}f}(Z_j - Zs_j) \end{cases},$$

which can be short for:

$$\begin{cases} X_j = Xs_j + \dfrac{U_j}{W_j}(Z_j - Zs_j) \\ Y_j = Ys_j + \dfrac{V_j}{W_j}(Z_j - Zs_j) \end{cases} \qquad (10)$$

It has consistent form as the collinear equations in ground photogrammetric coordinate system, but the content of coefficients are different, and ground points and satellite location are all coordinate values in geocentric coordinate system.

2.2 Adjustment model

2.2.1 Error equation for control points

If there is GCPs on combined adjustment image, such as GCP j (X_j, Y_j, Z_j) on image No. m and corresponding image coordinate (x_{mj}, y_{mj}), equations can be written according to Equation (10):

$$\begin{cases} f_{Xmj} = X_{smj}W_{mj} + (Z_j - Z_{sm})U_{mj} - X_j W_{mj} = 0 \\ f_{Ymj} = Y_{smj}W_{mj} + (Z_j - Z_{sm})V_{mj} - Y_j W_{mj} = 0 \end{cases}$$

(Xs Ys Zs) is the satellite location in earth-fixed geocentric coordinate system when image is acquired, errors equations of GCPs can be obtained after linearization:

$$\begin{cases} Vx_{mj} = \dfrac{\partial f_{Xmj}}{\partial \omega_m} d\omega_i + \dfrac{\partial f_{Xmj}}{\partial \varphi_m} d\varphi_m + \dfrac{\partial f_{Xmj}}{\partial k_m} dk_m - l_{xmj} \\ V_{Ymj} = \dfrac{\partial f_{Ymj}}{\partial \omega_m} d\omega_m + \dfrac{\partial f_{Ymj}}{\partial \varphi_m} d\varphi_m + \dfrac{\partial\partial f_{Ymj}}{\partial k_m} dk_m - l_{xmj} \\ l_{Xmj} = X_{sm}W_{mj} + (Z_j - Z_{sm})U_{mj} - X_j W_{mj} \\ l_{Ymj} = Y_{sm}W_{mj} + (Z_j - Z_{sm})V_{mj} - Y_j W_{mj} \end{cases} \qquad (11)$$

2.1.2 Error equation for connecting points

If image m overlaps with image n, and the connecting point is k, so the equations for connecting point can be written according to the same ground coordinate location of corresponding points:

$$\begin{cases} Y_k = Y_{S_{mk}} + \dfrac{V_{mk}}{W_{mk}}(Z_k - Z_{Sm}) = Y_{Snk} + \dfrac{V_{nk}}{W_{nk}}(Z_k - Z_{Sk}) \\ X_k = X_{S_{mk}} + \dfrac{U_{mk}}{W_{mk}}(Z_k - Z_{S_m}) = X_{Snk} + \dfrac{U_{nk}}{W_{nk}}(Z_k - Z_{Sk}) \end{cases}$$

Reduced equations can be formed after eliminating Z_k in two equations above:

$(V_{nk}W_{mk}-V_{mk}W_{nk})B_{Xk}-(U_{nk}W_{mk}-U_{mk}W_{nk})B_{Yk}=(U_{nk}V_{mk}-U_{mk}V_{nk})B_{Zk}$

Where $B_{Xk}=Xs_{mk}-Xs_{nk}$, $B_{Yk}=Ys_{mk}-Ys_{nk}$, $B_{Zk}=Zs_{mk}-Zs_{nk}$ if

$f_T(\varphi_m,\omega_m,\kappa_m,\varphi_n,\omega_n,\kappa_n)=$

$(V_{nk}W_{mk}-V_{mk}W_{nk})B_{Xk}-(U_{nk}W_{mk}-U_{mk}W_{nk})B_{Yk}-(U_{nk}V_{mk}-U_{mk}V_{nk})B_{Zk}=0$

By linearization, the error equation of virtual observation value related to connecting point can be formed as:

$$V_{Tk} = \frac{\partial f_c}{\partial \varphi_m} d\varphi_m + \frac{\partial f_c}{\partial \omega_m} d\omega_m + \frac{\partial f_c}{\partial \kappa_m} d\kappa_m + \frac{\partial f_c}{\partial \varphi_n} d\varphi_n + \frac{\partial f_c}{\partial \omega_n} d\omega_n + \frac{\partial f_c}{\partial \kappa_n} d\kappa_n + l_{Tk}$$

which can be short for:

$$V_{Tk} = B_{mk\omega}\Delta X_{mk\omega} + B_{nk\omega}\Delta X_{nk\omega} - L_{Tk} \qquad (13)$$

2.1.3 Combined adjustment

The error equation groups of remote sensing image based on position of camera station can be set up under the conditions of without or less GCPs when the accuracy of satellite position is high. The attitude of each image will be calculated together, achieve the aim of using less controls and connecting points between images to simplify the attitude angle elements of image. If connecting point between image m and image n is determined as i, meanwhile GCP on image l is j, equations could be shown as:

$$\begin{cases} V_{Ti} = B_{mi\omega}\Delta X_{mi\omega} + B_{ni\omega}\Delta X_{ni\omega} - L_{Ti} \\ V_{Xj} = B_{lj\omega}\Delta X_{lj\omega} - L_{Xj} \end{cases} \qquad (14)$$

The front formula is the error equation of connecting point, and the second is error equation of control point. Point j in formula can be used as GCP in overlapping area of multiply images, so an error equation of the GCP can be established for every image. In theory, the number and area of image are not restricted because collinear equations are set up in geocentric coordinate system, and if these are a small quantity of GCPs, the improvement of orientation accuracy from space for all relative images can be carried out by connecting points of images. The error equations have solutions and the solutions are stability when the location coordinates of satellite Xs, Ys, Zs are determined as known values. if error equations are set up by using attitude of satellite imaging as observation values with weight, and together with equation (14), the block adjustment error equation groups of remote sensing image with less control in geocentric coordinate system can be combined. Shown as equation (15), where V_T, V_X, V_W is individually relative virtual observation value of connecting point, GCPs and corrected vector of attitude angle; B is relative coefficient matrix; L is constant term; and P is weight matrix.

$$\begin{cases} V_T = B_T X_\omega - L_T ....P_T \\ V_X = B_X X_\omega - L_X ......P_X \\ V_w = E_\omega X_\omega - L_\omega ....P_\omega \end{cases} \qquad (15)$$

V_T , V_ω, V_X is individually error equation of virtual observation value of connecting point, attitude angle and GCPs above, which can be short for

V=AX+L Weight P (16)

Where, A is coefficient matrix and X is unknown parameter.

$$X = \left[d\varphi_1, d\omega_1, d\kappa_1, \cdots\cdots, d\varphi_n, d\omega_n, d\kappa_n \right]^T$$

The corrected value of exterior orientation angle element for each image can be solved according to the principle of least square.

$$X = (A^T PA)^{-1} A^T PL \qquad (17)$$

Finally, the value of exterior orientation angle element for each image can be obtained by computing of adjustment, and subsequent image rectification and image mosaic can be implemented.

3. TESTING

The model itself does not restrict number and coverage of image, but limit to data source, testing data use adjacent three views of images acquired by a returned scientific testing satellite, which are obtained after scanning frame film images, whose position relationships are shown in figure (2).

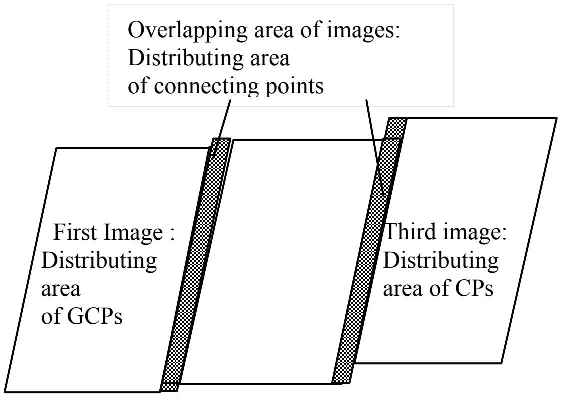

Figure 2: Distribution map of testing images

The images have higher orbit accuracy, but have lower attitude measurement accuracy because mount no gyroscope and UTS high-accuracy attitude measurement equipment. In testing, 8 GCPs are selected from first image, 10 corresponding connecting points are respectively selected from overlapping areas between first image and second image and also between second image and third image, and 10 checking points are selected from third image. Accuracy evaluation can be implemented based on checking points on third image under the condition of using from 0 GCP to 8 GCPs and all of connecting points respectively for computation. Which has to explain, due to all of the coordinates of GCPs and checking points are acquired from ortho-images, the planimetric accuracy is 5m, and there is no elevation data. But because of flat terrain for this area, the identical sketchy values are evaluated to the elevations of GCPs and checking points in process of computation, and this will bring some influences for testing accuracy. The errors and accuracy of checking points for third image in different testing conditions are listed in Table (1)

GCP Nums	0 GCP		1 GCP		2 GCPs		5 GCPs		8 GCPs	
Check point	ΔX (m)	ΔY (m)	ΔX (m)	ΔY (m)	ΔX (m)	ΔY (m)	ΔX (m)	ΔY (m)	ΔX (m)	ΔY (m)
1	-628	-1265	-30	-51	-22	-42	-3.2	-33	13.0	-27.2
2	-877	-1271	-19	-42	-18	-30	-4.3	-23	5.8	-18.5
3	-660	-1380	-31	-24	-24	-17	-6.1	-12	9.5	-11.3
4	-773	-1358	-24	-29	-20	-25	-4.7	-17	7.8	-15.4
5	-769	-1239	-27	-51	-22	-39	-6.2	-31	6.8	-25.9
6	-661	-1325	-27	-30	-20	-25	-2.1	-19	13.3	-16.7
7	-832	-1299	-19	-35	-16	-28	-2.0	-20	9.0	-17.3
8	-866	-1201	-10	-48	-8.	-37	5.8	-25	16.5	-18.2
9	-744	-1277	-27	-46	-22	-38	-5.3	-29	8.3	-23.8
10	-749	-1318	-28	-33	-23	-28	-6.6	-21	7.1	-14.1
m_x/m_y	760	1294	30	40	20	31	4.8	23.8	10.2	19.5

Table 1: Accuracy of combined adjustment with different numbers of GCPs

4. CONCLUSIONS

This paper has discussed combined adjustment of multi-images with satellite images. The model itself does not restrict geographic coverage of mult-images due to model is established in geocentric coordinate system, the function relations between connecting points have been reduced, and unknown connecting point coordinates in error equations have been eliminated, so as to a error equation is set up for each pair of connecting points. The coordinates of connecting points have not been used as unknown values entering into adjustment model, which is significant for reducing the number of error equations for large-scale of adjustment and size of sparse matrix.

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