AN EFFECTIVE METHODOLOGY OF USING GPS/IMU DATA FOR AUTOMATIC POINT TRANSFORMATION IN AERIAL TRIANGULATION

Yang Ming [a,*], Xiuxiao Yuan [a]

[a]School of Remote Sensing and Information Engineering, Wuhan University, 129 Luoyu Road, Wuhan 430079, China-(ankelbreaker)@163.com

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ABSTRACT:

In this paper, an efficient methodology using GPS/IMU data for automatic point transformation in aerial triangulation is presented. It firstly performs matching within each strip. For point transformation between strips, with the help of GPS/IMU data, tie point's initial position in search image of neighboring strips can be easily obtained, with high accuracy of several pixels. Then correlation window warping procedure and multi-image matching in image space is used for matching. The former is to reduce the effect of geometric distortion due to terrain relief and orientation difference and the latter is to take advantage of redundant information provided by the multiple overlapped images to reduce image matching blunders. Experiments have been carried out to verify the method. It have shown that by integrating the GPS/IMU data in the point transfer, it can not only simplify the point transferring procedure but improve the matching success rate of tie points between strips, providing relatively more robust geometry structure for the bundle block adjustment.

1. INTRODUCTION

Aerotriangulation is a well-established procedure for obtaining the exterior (and possibly the interior) orientation parameters for a set of aerial photographs. Its goal is to determine enough control points for orienting every stereo model. This is accomplished by using a relatively small number of ground control points (GCPs) (Kraus, 1993), which in turn reduces the cost of a photogrammetric mapping project considerably.

One of the major tasks in aerotriangulation is the measurement of conjugate points on two or more partially overlapping photographs. These points tie the photograph together. The exterior orientation parameters of all the photographs are then calculated simultaneously according to a known mathematical model (Ayeni, 1982).

With the trend towards digital photogrammetry and the use of digital photogrammetry workstations, the automation of aerotriangulation process has been under research for decades. Several researchers have reported attempts to automate aerotriangulation (Agouris, 1992; Ackermann and Tsingas 1994; Krupnik, 1994; Krupnik and Schenk, 1997).

In the recent years, the integrated position and orientation system (POS) has undergone major research and development (Jacobsen, 2000; Heipke, 2000; Cramer and Stallmann, 2002; Cramer, 2003). There are two pattern for the POS-supported aerial georeferencing, one is called direct georeferencing (DG), which take advantage of the calibration field to compensate the system error in POS system, and get the total block images' exterior orientation elements. The characteristics of DG is getting rid of the traditional model of aerotriangulation, but the accuracy cannot meet the demand for large scale mapping; the other is integrated sensor orientation (ISO), which can provide high accuracy positioning and orientation result, but still need performing point transferring in the whole block.

In this context, discussing how to make use of the result of DG to facilitate the procedure of point transferring has very realistic meaning. After detailed analysis the influence of errors in exterior orientation elements and uncertainty in object space, we present a very efficient way to simplify the point transferring procedure and improve the success rate of image matching. Experiments have been carried out to verify the method proposed in this paper, and the results are elaborately analyzed. Overview of the point transfer method

The procedure of point transformation in aerotriangulation can be divided into two parts: one is the point transferring within each strip, and the other is point transferring between neighboring strips.

For the first part, we elaborate it as follows: for each image in the strip, the overlapped area with neighboring images are determined and the interest points are extracted by using some operator, like Förstner, then perform matching through pyramid levels, the matching results of the high level is used to guide and restrict the matching in the next pyramid, and after finishing matching in each pyramid level, blunder detection is performed by relative orientation procedure with iterative weight method. Repeating it until reaching the original image level, the Least Square Matching (LSM) is carried out to refine the accuracy to the sub-pixel level.

After matching in each strip, the matching between neighboring strips is followed to obtain the tie points of the block. Due to accurate and robust matching in the first part, we can assume the coordinates of conjugate points are correct. By using the exterior orientation elements (EO) provided by POS system, forward intersection is performed to get the point's object coordinates, then using the collinearity equation we can project the point to the search images in the neighboring strip. After that, the tie point approximate position is obtained and multi-image matching in image space is followed. Through the similar steps of matching in strip, the tie point's accurate position can be determined. The workflow of point transfer method is depicted in Fig. 1.

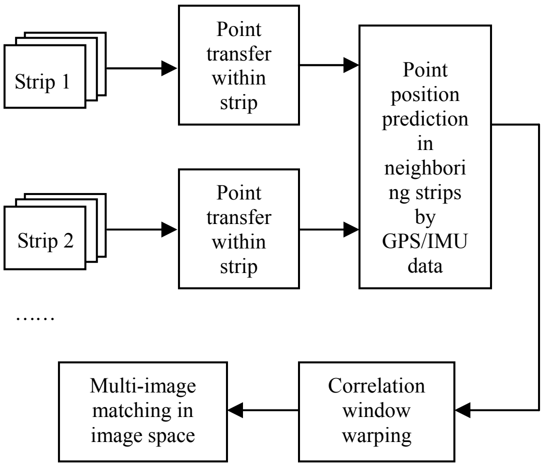


Fig.1 Workflow of point transfer method

2. MATCHING METHOD

3.1 Tie Point Approximation Prediction Based on the POS data

A fundamental aspect of matching is to predict the matching locations and reduce the matching range. Assuming we have selected a tie point, in order to perform the following the multiple image matching in image space, we need approximate locations on all corresponding images.

3.1.1 Prediction Accuracy Analysis

(X, Y, Z) is the object coordinate of the tie point, (x, y) is the image coordinate, $(X_s, Y_s, Z_s, \phi, \omega, \kappa)$ is the EO of the predicted image provided by POS system. Linearizing the colinearity equation with (X, Y, Z) and $(X_s, Y_s, Z_s, \phi, \omega, \kappa)$, equation (1) can be gotten:

$$dx = \frac{\partial x}{\partial X}dX + \frac{\partial x}{\partial Y}dY + \frac{\partial x}{\partial Z}dZ + \frac{\partial x}{\partial X_S}dX_S + \frac{\partial x}{\partial Y_S}dY_S + \frac{\partial x}{\partial Z_S}dZ_S + \frac{\partial x}{\partial \phi}d\phi + \frac{\partial x}{\partial \omega}d\omega + \frac{\partial x}{\partial \kappa}d\kappa$$
$$dy = \frac{\partial y}{\partial X}dX + \frac{\partial y}{\partial Y}dY + \frac{\partial y}{\partial Z}dZ + \frac{\partial y}{\partial X_S}dX_S + \frac{\partial y}{\partial Y_S}dY_S + \frac{\partial y}{\partial Z_S}dZ_S + \frac{\partial y}{\partial \phi}d\phi + \frac{\partial y}{\partial \omega}d\omega + \frac{\partial y}{\partial \kappa}d\kappa \quad (1)$$

In vertical photography, when all the angular orientation elements are small angles, and $\phi = \omega = \kappa = 0$ can be substituted into the coefficients as their respective approximate values, then the values of all the coefficients in Eq.(1) are:

$$\frac{\partial x}{\partial X_S} = -\frac{\partial x}{\partial X} = -\frac{f}{H}, \quad \frac{\partial x}{\partial Y_s} = -\frac{\partial x}{\partial Y} = 0, \quad \frac{\partial x}{\partial Z_S} = -\frac{\partial x}{\partial Z} = -\frac{x}{H},$$

$$\frac{\partial y}{\partial X_S} = -\frac{\partial y}{\partial X} = 0, \quad \frac{\partial y}{\partial Y_S} = -\frac{\partial y}{\partial Y} = -\frac{f}{H}, \quad \frac{\partial y}{\partial Z_S} = -\frac{\partial y}{\partial Z} = -\frac{y}{H},$$

$$\frac{\partial x}{\partial \phi} = -f(1+\frac{x^2}{f^2}), \quad \frac{\partial x}{\partial \omega} = -\frac{xy}{f}, \quad \frac{\partial x}{\partial \kappa} = y,$$

$$\frac{\partial y}{\partial \phi} = -\frac{xy}{f}, \quad \frac{\partial y}{\partial \omega} = -f(1+\frac{y^2}{f^2}), \quad \frac{\partial y}{\partial \kappa} = -x$$

From the coefficients, we can see that, the influence of linear elements on prediction error is proportional to the image scale, that the larger the image scale the stronger the influence. However, the influence of angular elements is more complicated, having relationship with the position in the image of tie point and the focal length. The tie point nearest the image edge has the worst prediction accuracy.

Given a point at image margin x=100mm, y=100mm, the focal length is 303.64mm, the image scale is 1:3000, the pixel size is 21um. The 0.1m error in X_s, Y_s will lead to 1.3pixels prediction error, and 0.1m error in Z_s corresponding to about 0.4 pixels. For 0.005° error in φ, it will produce an error of 1.2 pixels and 0.1 pixels respectively in *x* and *y* direction; for ω, 0.1 pixels and 1.2 pixels, and for κ, 0.4 pixels and 0.4 pixels. For 0.5m error in the object coordinate *X*, *Y*, the influence in its direction is 6.5 pixels, and no influence in vertical direction; for same error in Z, the prediction error is about 2 pixels.

Through the above analysis, the following conclusions can be summarized: firstly, due to the relatively high accurate EO of DG, the error in the object coordinates of the tie points has the strongest influence in the prediction. Secondly, if relatively accurate object coordinates can be gotten, taking consideration of mutual influence of different error sources and the tie point actual position in the image, we predication precision is several pixels.

3.1.2 Tie Point Approximation Prediction

After matching in each strip, the image coordinate of tie points can be assumed accurate. In order to alleviate the effect of error of object coordinates on predication precision, it is calculated through multi-ray intersection. Then making use of collinearity equation to project it into the search image, the initial position is obtained. So the predication precision is mainly depended on the quality of EO, and an accuracy of a few pixels is expected. With the help of GPS/IMU data, the procedure of model connection and reconstruction of free strip net is no longer need, which simplifies the process of point transferring between the strips.

3.2 Correlation Window Warping Procedure

When terrain undulation or the flight direction difference is large, even the accurate prediction position can be provided the geometric distortion in image will still lead to the matching failure or the deterioration of matching quality. To reduce the effect of geometry distortion due to the relief and orientation, correlation window warping procedure is adopted.

As we now have the approximate height of tie point, and all images' EO, we can use them to compensate partial geometry distortion and improve the matching success rate. It implements as follows: firstly, the corresponding pixel coordinates of the 4 corner of the correlation window in the search images are computed, and the coordinates for other pixels within the correlation window can be interpolated by using the bilinear interpolation method, finally their grey values are interpolated from the search images again by using the bilinear interpolation method. The match is performed between the warped correlation windows. In this simplified implementation, the object surface patch's corresponding correlation window is assumed to be a local planar surface. In most cases, this assumption is justified because the object surface can be treated as piecewise smooth surface.

3.3 Multi-image Matching in Image Space

To resolve the ill-posed problem in image matching, we should make full use of the redundant information provided by the multiple overlapped images to reduce image matching blunders to the smallest degree. In this paper, we adopt the normalized cross correlation (NCC) as the similarity measure, when we have multiple overlapping images, the conjugate points should get greater support from other images, and the incorrect matches will get little support, through calculated the average NCC, the point with the largest average NCC is considered as the conjugate point, which can efficiently enhance the matching reliability.

3. EXPERIMENT AND RESULTS

We have carried out point transfer experiment on real aerial images block for verification. The aerial images used are obtained by the Leica RC-30 aerial surveying camera with airborne POS system. Before the aerial photography, has installed Canadian Applanix Corporation's POS AV 510 system on the aerial surveying camera, and mounted Novltal dual-frequency aviation GPS antenna on the top of domestic airplane transported – 12. During the aerial photography, on the airplane POS system internal GPS receiver was used, in the block's two base stations each has placed one Trimble 5700 dual frequency GPS receiver, and the data updating rate is set as 0.5 seconds. Before the airplane launching carried on the 10min initialization, after the airplane landing has carried on the 5 minutes static observation.

The dataset consists of 6 strips, and 10 images for each strip. The photographic scale is 1:3000, focal length is 303.64mm, pixel size is 21um, and the largest relief undulation is 96.02 meters. The POS EO used has been made system error compensation.

4.1 Predication Accuracy Experiment

The final matching results have the accuracy of sub-pixel level which can be taken as the "truth", compared them with the predicted position, the prediction error can be obtained. Statistics analysis of prediction error is performed and the prediction accuracy is gotten. Table 1 is the results of some images which are at the beginning, in the middle and at the end of the strip.

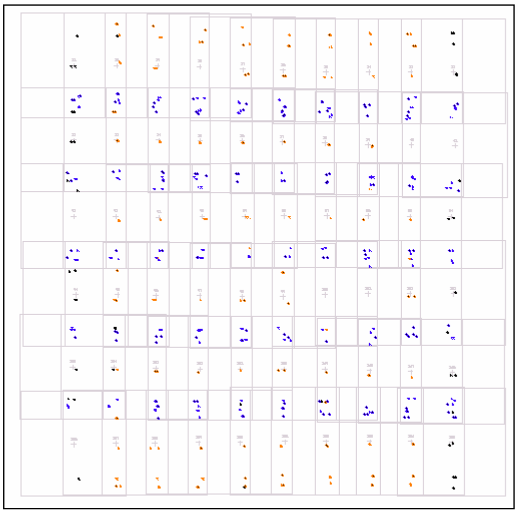
From the Table 1, we find that by using the calibrated POS exterior orientation elements, we predict the tie points to the neighboring strips with an average accuracy of about 5 to 7 pixels in *x* direction and 1 to 4 pixels in *y* direction. This largely reduces the search range for the following matching, not only improve the matching efficiency, save the matching time, but also have the potential to improve the matching reliability.

stereo model	Minimum prediction error		Maximum prediction error		Prediction accuracy	
	x	*y*	*x*	*y*	*x*	*y*
101-201	2.3	0.0	4.8	8.8	3.4	0.8
103-203	2.6	0.0	5.1	4.3	3.6	1.3
105-205	0.4	0.0	3.1	3.1	2.0	1.3
107-207	0.8	0.0	4.7	6.0	2.8	1.6
109-209	1.9	0.0	5.1	6.0	3.3	1.4
301-401	4.7	0.0	7.4	9.5	5.9	3.3
303-403	5.4	0.0	8.5	6.4	6.8	1.7
305-405	2.8	0.0	8.1	8.6	6.4	1.7
307-407	5.1	0.0	7.8	4.1	6.3	0.8
309-409	3.8	0.0	8.6	6.2	6.0	1.2

Tab.1 Statistics results of Point Prediction (Pixels)

4.2 Point Transfer experiment

After point transferring with the method proposed in this paper, we extract the standard tie points with the distribution model of 5×2, that is evenly placing five standard positions in the center of overlapped area and at each position two points are extracted. Because the side overlap is about 35% in the experiment, we can calculate that the tie points between the strips should occupy 66.7 percent in the total number. Fig.2 is the overview of the point transferring results.



● tie point between strips ● tie point within strip

Fig. 2 Overview of the point transfer results

From the Fig. 2, we can clearly see that, for the common area of neighboring strips have the majority of the tie points between strips, and only for the area not overlapped by the strips, the tie points within the strip are dominant. This structure guarantees the robust block geometry and good block adjustment results.

Point emerging image number	Number of points	Percent (%)
2	41	8.506
3	156	32.365
4	60	12.448
5	111	23.029
6	114	23.651

Table 2 is the overlap information of tie points

Because the forward overlap is 60%, we can assume the point whose emerging image number is more than 3 is the tie point between the strips. From the data in Table 2, we find that the percent of tie points between strips is about 59.1%, which is very near to the theoretical value 66.7%. The good results benefit from two aspects: one is the approximate position prediction by GPS/IMU data, which has nearly several pixels accuracy, largely reduce the search range for matching, not only saving the match cost, but improve the matching reliability and success rate; the other is correlation window warping and multi-image matching, which firstly resample the correlation window to reduce the geometry distortion in image, and then use the redundant information from multiple overlapping images to find the correct match, these obviously improve the matching success and reliability.

We can also see that most of the tie points between strips emerge on five or six images, it verified that this method can efficiently improve the success rate of point transfer, enlarge the percent of tie points between strips in total number, and correspondingly can reconstruct relatively more robust block geometry for block adjustment.

4. CONCLUSIONS

In this paper, we have proposed an efficient methodology of using GPS/IMU data for point transfer in aerial triangulation. By using the GPS/IMU data, the tie point can be easily projected onto the search images in the neighboring strips, getting rid of the procedure of model connection and reconstruction of free strip, and it enables us to perform the correlation window warping procedure to reduce the effect of geometry distortion. Through multi-image matching in image space, the tie points between strips are obtained. Experiments have been performed and the results have shown that this method can efficiently simplify the point transferring procedure, improve the success rate of point transfer, enlarge the percent of tie points between strips in total number, and correspondingly can reconstruct relatively more robust block geometry for block adjustment.

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REFERENCES

Ackermann E., Tsingas V. 1994. Automatic digital aerial triangulation. *Proceedings of ACSM/ASPRS Annual Convention*, Reno, NV, Vol. 1, pp.1-12.

Agouris E., 1992. *Multiple image multipoint matching for automatic aerotriangulation*. PhD thesis, Department of Geodetic Science and Surveying, The Ohio State University, Columbus.

Ayeni O.O. 1982. Phototriangulation: A review and bibliography. *Photogrammetry Engineering and Remote Sensing*, 49(11), pp.1733-1759.

Cramer M. 2003. Integrated GPS/Inertial and digital aerial triangulation – recent test results, *Proceedings of Photogrammetric Week*, Stuttgart.

Cramer M., Stallmann D. 2002. System calibration for direct georeferencing. *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIV, Part 3A, pp 79-84.

Heipke C., Jacobsen K., Wegmann, et al. 2000. Integrated sensor orientation – an OEEPE test. *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Amsterdam.

Jacobsen K. 2000. Potential and Limitation of Direct Sensor Orientation. *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Amsterdam.

Krans K. 1993. *Photogrammetry* (4th Ed). Diimmler, Bonn.

Krupnik A. 1994. *Multiple-patch matching in the object space for aerotriangulation*. Technical Report 428, Department ofGeodetic Science and Surveying, The Ohio State University, Columbus.

Krupnik A., Schenk T. 1997. Experiments With Matching in the Object Space for Aerotriangulation. *ISPRS Journal of Photogrammetry and Remote Sensing*, 52(1), pp.160-168.