THE ERROR ANALYSIS AND CORRECTION METHOD RESEARCH OF THE ATTITUDE DATA FOR THE UAV REMOTE SENSING IMAGES

Hongying Zhao [a, *], Yuanchen Qi [b]

[a] Institute of Remote Sensing & Geographic Information System, Peking University, Beijing 100871, China - zhaohy@pku.edu.cn
[b] College of Surveying and Geographical Science, Liaoning Technical University, Fuxin 123000, China - qiyuanchen649@163.com

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ABSTRACT:

As an important way to obtain the high-resolution remote sensing images, the unmanned aerial vehicle (UAV) aviation remote sensing plays a more and more important role in the area of photogrammetry and remote sensing application. The correction of the UAV remote sensing images without the ground control points needs high-resolution attitude data. The original attitude data can be obtained from the UAV airborne GPS/INS. The attitude data error analysis and correction method is proposed, and the corresponding error calibration mode is established in this paper. The images of the UAV aerial photography is used to verify the effectiveness and feasibility of this model, and the experimental results show that the UAV aerial remote sensing images can realize high-precision correction without the ground control points.

1. INTRODUCTION

With the rapid development of civil remote sensing recently, the demand for remote sensing image is increasing, especially large-scale and high-resolution remote sensing images. At present, the main information acquisition platforms of the world are still satellite and manned plane. The shortcomings of the satellite remote sensing platform are high price and long return cycle, so when high-resolution images are got, the update speed of the images is slow. While the manned-plane remote sensing system is mainly limited by rising-landing and safety condition, it is unable to satisfy the users' requests about safety. As a new and effective type of earth observation system, the UAV remote sensing information platform is proposed to obtain remote sensing images at present. Its main characteristics are as follows: 1. Without considering human factors by auto-control flight; 2. The flight mode is flexible and have long flight time; 3. High flight trajectory precision; 4. Flying under the clouds. These characteristics enable the UAV aviation remote sensing information platform to become an effective supplement way to the satellite and manned-plane remote sensing

UAV can realize auto-control flight as an aviation remote sensing platform, and the position and attitude data of the airplane can be obtained directly through the airborne GPS/INS integrated navigation system. But if we regard this group of posture data as the corrected exterior orientation elements for the images, it must carry on coordinate transformation (Naci Yastikli, 2005) and systematic error compensation in order to convert the aircraft attitude data obtained from inertial navigation system to the high-precision exterior orientation elements for the images. This systematic error mainly refers to the spatial displacements and the deviation angle error. Though the spatial displacement between the GPS antenna phase centre and the camera projection center is easy to get, the deviation angle error can't be determined directly through the traditional method. This error seriously affects the correction precision of the UAV remote sensing images.

At present, in aerial photogrammetry assisted by the manned-plane airborne GPS/INS, two calibration methods are generally used to correct the deviation angle error. One way is that the ground control points is firstly laid out in the survey area, then each photo's exterior orientation elements directly obtained from GPS/INS as weighted observation value participate in the photogrammetry block adjustment. So we can obtain higher precision exterior orientation elements for the images; another method is that the region which includes two (or more) flight strips in or near the survey area as calibration field is firstly selected, then the exterior orientation element of each aerial photo is exactly determined through the method of aerial triangulation. After that, matrix operation is carried out using the exterior orientation elements computed above and observation values including deviation angle error obtained from the GPS/INS system, then the deviation angle error can be got. This way is called direct orientation method. The first way needs to lay out ground control points in the whole operation range, which not only restricts operation range, but also decreases work efficiency and enlarges the cost of operation. Based on the second way, according to the UAV's operation standard and corresponding instrument indexes, in this paper the attitude data correction mathematical model of the UAV aerial remote sensing image is established and the right deviation angle error is calculated. So the original aerial attitude data obtained from the GPS/INS system can be transformed to the images' exterior orientation elements which are needed for direct georeferencing in aerial photogrammetry.

* Corresponding author.

2. SYSTEMATIC ERROR CORRECTION MODEL FOR THE UAV AIRBORNE GPS/INS

The UAV airborne GPS/INS integrated navigation system is a position and azimuth determining system composed of GPS receiver and Inertial Measurement Unit (IMU), it can be used to obtain the moving vehicle's spatial three-dimensional position and attitude data.

2.1 Coordinate System Transformation

The original attitude data (θ, ϕ, ψ) acquired from UAV airborne IMU is the corresponding coordinate axes' angles between IMU Coordinates System and Navigation Coordinates System (moving); while the exterior orientation elements of the images $(\varphi, \omega, \kappa)$ is the corresponding coordinate axes' angles between image Coordinates System and terrestrial photogrammetry coordinates system. Therefore, we must first transform the UAV airborne IMU attitude data (θ, ϕ, ψ) from navigation coordinates system (moving) to terrestrial photogrammetry coordinates system in order to obtain the exterior orientation elements of the images(Bäumker, 2002). Figure 1 shows the concrete conversion process.

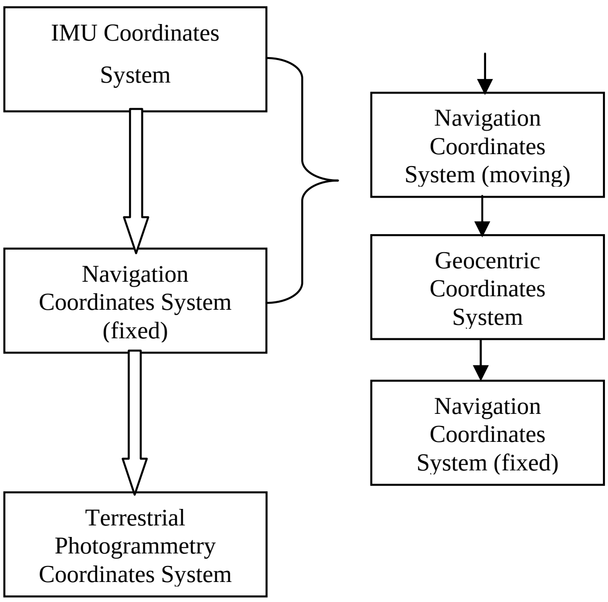

Figure 1. The flow chart of coordinate transformation for UAV attitude data

2.2 Deviation Angle Error

For apparatus installation technology's reasons, the axes of IMU coordinates system aren't exactly parallel to that of camera coordinates system when installing. Generally there exists exiguous angle deviation ($<3^\circ$) between the corresponding axes of this two coordinates. We call it deviation angle error usually (Figure 2). In Figure 2, x_b, y_b, z_b respectively represents three axes of IMU coordinate system, and x_c, y_c, z_c respectively represents three axes of camera coordinate system. Camera coordinates system separately rotates α_z 、 α_y 、 α_x around the z axis、y axis and x axis relatively to IMU coordinate system. This group of deviation angle error can't be determined directly by the conventional measurement method, so other methods are needed to use to obtain them.

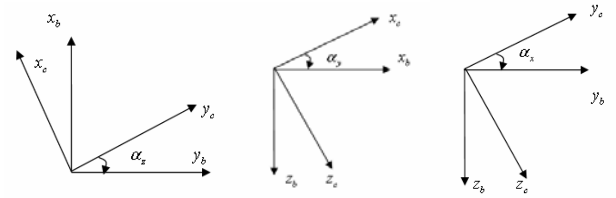

Figure 2. Deviation angles from camera coordinate to IMU coordinate

2.3 Deviation Angle Error Correction Model

Images' exterior orientation elements obtained after coordinate system transformation are still affected by the deviation angle error. This error can't be acquired through the conventional measurement method, so the images which have known exterior orientation elements can be utilized to obtain this error indirectly. First, one calibration region which has enough quantity and precision ground control points is selected to proceed calibration flight, then the exterior orientation element of each image is calculated by the conventional method. Finally, the best estimated value of the deviation angle error $(\alpha_x, \alpha_y, \alpha_z)$ is calculated using the exterior orientation elements computed above and the original attitude data obtained from IMU. The concrete computing process is as follows.

Ⅰ According to this group of deviation angle error $(\alpha_x, \alpha_y, \alpha_z)$, the rotation matrix R_c^b from camera coordinate system c to IMU coordinate system b is established. And because α_z 、 α_y 、 α_x are all less than 3° , this matrix can be simplified according to the related knowledge of inertial navigation(Skaloud, 2003).

$$
\begin{aligned}
R_c^b &= R_y(\alpha_y)\cdot R_x(\alpha_x)\cdot R_z(\alpha_z)\\
&= \begin{bmatrix} \cos\alpha_x & 0 & -\sin\alpha_x \\ 0 & 1 & 0 \\ \sin\alpha_x & 0 & \cos\alpha_x \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha_y & -\sin\alpha_y \\ 0 & \sin\alpha_y & \cos\alpha_y \end{bmatrix} \cdot \begin{bmatrix} \cos\alpha_z & -\sin\alpha_z & 0 \\ \sin\alpha_z & \cos\alpha_z & 0 \\ 0 & 0 & 1 \end{bmatrix}\\
&= \begin{bmatrix} 1 & -\alpha_z & -\alpha_y \\ \alpha_z & 1 & -\alpha_x \\ \alpha_y & \alpha_x & 1 \end{bmatrix}
\end{aligned} \tag{1}
$$

Ⅱ According to the flow chart of coordinate transformation in Figure 1, the rotation matrix R_c^L from camera coordinate system c to terrestrial photogrammetry coordinate system L is set up. R_b^L is the rotation matrix from IMU coordinate system to terrestrial photogrammetry coordinates system. Thus, we can get formula (2) and (3).

$$R_c^L = R_b^L \cdot R_c^b = R_y(\varphi)\cdot R_x(\omega)\cdot R_z(\kappa) \quad (2)$$

$$R_b^L = R_y(\theta)\cdot R_x(\phi)\cdot R_z(\psi) \quad (3)$$

III In formula (2), the other parts can be all computed except R_c^b, and the elements in R_c^b are just the deviation angle error, which are we want to calculate. After expanding this formula, we can get a set of observation equations $AX = L$ about $(\alpha_x, \alpha_y, \alpha_z)$, where $X = (\alpha_x, \alpha_y, \alpha_z)^{\mathrm{T}}$ is the unknown quantity, and the corresponding error equations is $V = AX - L$. For each image i, a set of $V_i = A_i X - L_i$ can be list out. According to s the related knowledge of surveying adjustment, we can know $X = (A^{\mathrm{T}} \cdot A)^{-1} \cdot A^{\mathrm{T}} \cdot L$. Supposed that there are two images, then

$$X = \left(\begin{pmatrix} A_1 \\ A_2 \end{pmatrix}^{\mathrm{T}} \cdot \begin{pmatrix} A_1 \\ A_2 \end{pmatrix} \right)^{-1} \cdot \begin{pmatrix} A_1 \\ A_2 \end{pmatrix}^{\mathrm{T}} \cdot \begin{pmatrix} L_1 \\ L_2 \end{pmatrix} = \left(A_1^{\mathrm{T}} \cdot A_1 + A_2^{\mathrm{T}} \cdot A_2 \right)^{-1} \cdot \left(A_1^{\mathrm{T}} \cdot L_1 + A_2^{\mathrm{T}} \cdot L_2 \right) \quad (4)$$

and so on. Thus the deviation angle error $(\alpha_x, \alpha_y, \alpha_z)$ between IMU coordinate system and camera coordinate system can be obtained.
We can use this group of error through formula (2) to correct the IMU attitude data which have been transformed in the terrestrial photogrammetry coordinates system, in order to acquire the higher precision exterior orientation elements of the UAV images. Thus we complete correcting the original attitude data obtained from the UAV airborne GPS/INS inertial navigation system.

3. RESULT ANALYSIS OF EXPERIMENTAL DATA

A set of UAV aerial remote sensing images, which are shot on August, 2005 in Anshun, Guizhou province, are tested in this paper. Main performance indexes of the UAV remote sensing system adopted in this shooting are as follows. Operation height: 1.5km; endurance velocity: 170km/h; maximum endurance time: 30h; navigation accuracy: 50m; effective load: 60kg etc. This UAV remote sensing platform is composed of three sub-modules: UAV platform; camera subsystem; aerial remote sensing control subsystem. Among them, UAV platform is responsible for flight mission; camera subsystem is responsible for exposure and storage of original data of images; and aerial remote sensing control subsystem is responsible for controlling camera's trigger and the data transmission between camera system and UAV platform. The images in this flight experiment are shot according to time, and the shooting interval t=5s; focal length f=83.112mm. Table 1 lists out partial results of original attitude data in terrestrial photogrammetry coordinates system for IMU.

According to the deviation angle error correction method proposed in this paper, regarding the results computed by

Image Number	Original Data for IMU in Terrestrial Photogrammetry Coordinate System		
	Phi/deg	Omega/deg	Kappa/deg
158	-1.612115	-0.439668	2.813874
157	-1.582804	0.263801	2.901808
156	-2.066439	-0.146556	2.638007
155	-2.418173	0.644846	2.550073
154	-2.066439	-1.055203	2. 72594
62	-1.568148	-0.23449	1.494871
61	-2.169028	-0.820713	1.406937
60	-1.025892	-1.846605	2.110405
59	-1.875916	-0.99658	2.813874
58	-2.037127	-1.289692	2.813874

Table 1. Attitude data from IMU in terrestrial photogrammetry coordinates system

resection as true value, we make whole adjustment on the data, and the result is $(\alpha_x, \alpha_y, \alpha_z) = (-0.2464^{\circ}, -0.5959^{\circ}, 0.4927^{\circ})$ .The n the attitude data of the images shot in this flight experiment are corrected using this error. Table 2 lists out partial calibration results and the results calculated through resection. After that we can compare these calibration results and the original attitude data with the results computed by resection. Figure 3, Figure 4 and Figure 5 list out the comparative results.

Image Number	Corrected Results Computed by Deviation Angle Errors			Results Computed by Resection(True Value)		
	Phi/deg	Omega/deg	Kappa/deg	Phi/deg	Omega/deg	Kappa/deg
158	-2.1944	-0.7105	3.306	-2.6632	-0.757	3.7558
157	-2.1658	0.1556	3.3976	-3.8457	0.1343	3.8388
156	-2.6528	-0.4183	3.1283	-2.7834	-0.4375	3.7432
155	-3.0023	0.3724	3.3174	-2.7665	0.3924	3.1443
154	-2.6528	-1.3293	3.2086	-2.0373	-0.9258	3.1881
62	-2.1601	-0.4927	1.9882	-2.0578	-0.4544	1.8221
61	-2.7617	-1.0772	1.8908	-2.6543	-1.0235	1.7332
60	-1.6157	-2.1142	2.584	-1.3873	-1.9719	2.6542
59	-2.458	-1.272	3.3002	-2.3911	-1.1574	3.5212
58	-2.6241	-1.5642	3.2945	-2.5476	-1.4427	3.1458

Table 2. The corrected attitude data and the results calculated by resection

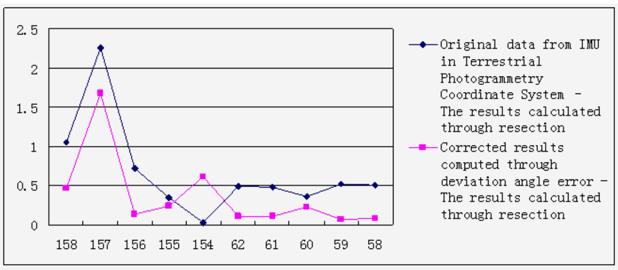

Figure 3. The comparative results of Phi between the original attitude data and the corrected attitude data

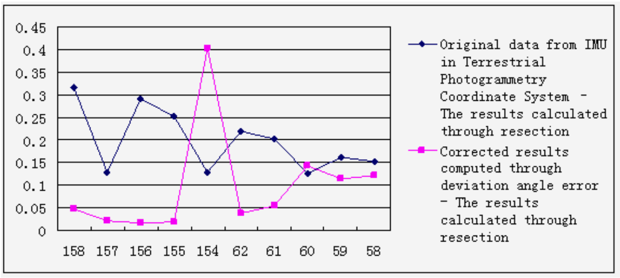

Figure 4. The comparative results of Omega between the original attitude data and the corrected attitude data

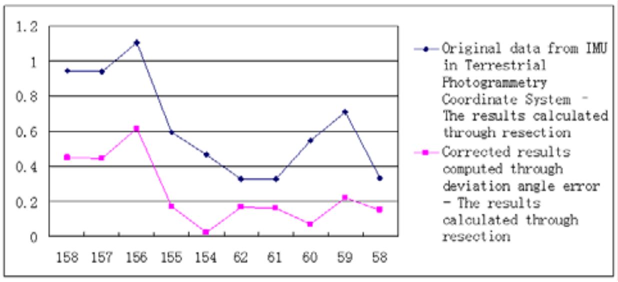

Figure 5. The comparative results of Kappa between the original attitude data and the corrected attitude data

Through analyzing Figure 3, Figure 4 and Figure5, we can find the UAV remote sensing images attitude data correction model proposed in this paper improves the precision of images' attitude data. But the accuracy of the deviation angle error is affected by systematic error of GPS / IMU, such as the error of gyro random drift. So the systematic error correction model for gyro random drift will be established to obtain higher precision deviation angle error in the future studies.

4. CONCLUSIONS

In this paper, the error calibration model of the UAV airborne attitude data is established, then the model is tested through a set of UAV aerial remote sensing images. Experimental results show that the model can effectively correct the original attitude data acquired from the GPS/INS. Meanwhile, from the data analysis we can see that the accuracy of deviation angle error is affected by other systematic errors of the GPS / IMU, such as the error of gyro random drift etc. So the systematic error correction model for gyro random drift will be established to obtain higher precision deviation angle error in the future studies.

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