Research on Key Technology of UAV Low-altitude Photogrammetry

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Abstract. Photographic field control measurement is divided into the measurement of the basic control points of the regional network and the simultaneous measurement of the image control points and checkpoints. The main purpose is to connect the aerial camera coordinates with the ground control points, and then measure the plane according to the mathematical model. The accuracy of the point and elevation points, which in turn reflects the accuracy of the DOM digital product. Image control data directly reflects the accuracy of digital products. Therefore, it is necessary to perform joint control of image points. This paper mainly studies the key technologies of field control point layout and joint measurement, aerial triangulation and digital product generation.

1. Introduction
Photographic field measurement operations include the development of joint testing plans, field survey sites, field observations and calculations to obtain control results. Image control points have extraordinary significance in positioning and calibration in aerial survey mapping. Image control points need to be imaged first. The film is laid on the film, and then the apparent object is connected in the field measurement area to measure the parallel image, and the plane and elevation coordinate values of the point are obtained.

2. Photographic field control measurement method

2.1. Photo control point layout
Photograph control point layout is generally divided into all-field layout and non-full field layout. The whole field layout is generally used for patch correction or for stereo mapping. The control points are all measured by the field. Usually, the non-full field deployment plan is adopted, which is divided into the layout scheme of the airborne network method and the layout scheme of the regional network.

(A). Airline network method
The navigation network method is often set up on the basis of the navigation belt to establish the control point. The empty three encryption points will generate the error superposition. In order to prevent the error doubling, the correction is usually based on the distance between the control points and the number of the interval baseline. Plane points and elevation points have different requirements.
The heading cross-count of the picture control point can be calculated according to formula (1) and formula (2).

\[ m_s = \pm 0.28 \times Tm_q \sqrt{n^3 + 2n + 46} \]  
\[ m_h = \pm 0.088 \times \frac{H}{b} m_q \sqrt{n^3 + 23n + 100} \]  

The heading span requirements for the adjacent plane control points are shown in Table 1.

| Scale     | Number of routes |
|-----------|------------------|
| 1:500     | 4-5              |
| 1:1000    | 4-5              |
| 1:2000    | 5-6              |

There are three ways to arrange the airborne network method, six-point, five-point, and eight-point. These three layout methods, the number of spaced baselines between adjacent image control points, need to meet the accuracy requirements of the mapping, according to the formula (1) and formula (2) estimate.

(a). Six points. A pair of plane elevation points are established at the upper and lower overlapping areas of the two ends of each route. It is suitable to use the incomplete binary quadratic polynomial to make nonlinear corrections to the navigation network.

(b). Five points. The length of a certain flight network is less than a quarter of the length limit, but greater than one-half of the short-haul network, that is, a plane elevation point is set up above and below the midpoint of the air-belt network.

(c). Eight-point style. Eight plane elevation points are set up on each pair of routes.

(B). Regional network method

The regional network distribution method is to arrange plane elevation points at the four corners of the area network, and then add an elevation point in the middle area. When the side overlap of the image is small, the elevation point should be increased in the overlap area. When the side overlap of the survey route meets the requirements, there should be less than 6 routes. When the beam method is used to adjust the regional network, plane elevation points and elevation points are set at four corners of the area, and double-level high points are set at important positions.

2.2. Photo control point joint measurement

Photograph control point joint measurement is a method of measuring the plane point coordinates and elevation of a photo control point by combining a ground control point with a large location. The control points can be measured with RTK and total station. The RTK is generally centimeter-level accuracy and the total station can achieve millimeter-level accuracy.

In this paper, the southern CORS-RTK measurement is used, and the Pix4D Mapper software is used to perform the point-of-spot operation of the image control point. Firstly, the CORS point measurement is uniformly distributed in the school's south campus. A total of 3 navigation belts are measured, 15 control points are measured, and 30 inspections are performed. Point, because the school area base station signal is very poor, the last 11 control points remaining, 17 checkpoints are valid.

A total of 11 effective control points are deployed in the survey area. Using RTK-CORS method to measure, first connect Bluetooth in the range of the school base station, then set the hand thin coordinate system to WGS-84, joint photo coordinates and control point coordinates, calculate the accuracy of the image control point.
In the coordinate projection, in order to avoid the negative value of the coordinates, a fixed value is added to the east and north directions, the X value is added by 500 km, and the coordinate error is automatically generated by the Pix4DMapper software.

As can be seen from the table, the C point error is large, which may be caused by the signal of the CORS base station, or it may be because the alignment is not accurate enough. The aerial photograph is the image data obtained by the aerial photography camera, and the image point to the ground point is obtained through the center projection of the lens, so that the projection difference is generated on the undulating ground.

The calculation formula for the projection difference is:

\[ \delta h = \frac{\Delta h}{H_r} \times r \]  

(3)

3. Beam method regional network aerial triangulation

Air triangle processing is another key technology for UAV image processing. By using the image points taken from the image and the control points measured on the ground, the images can be integrated into the same object coordinate system. The object coordinates of the triangle-encrypted point and the outer orientation element of the picture. The goal is to add absolute directional image points for images with a small number of field measurement control points. Since the beam method is determined by using the actual measured image point coordinates to create an error equation for the observation value, the error of the distribution point is the lowest, so the beam method regional aerial triangulation is generally used.

The basic idea of the beam method regional network adjustment is to use the beam of each image as the minimum unit to create a central projection collinear equation. The coordinate values of the common intersections of adjacent images are equal, and the internal coordinates and field coordinates of the image control points are equal. Under the condition, the error equations of the control point and the encryption point are written, and the unified adjustment processing of the entire region is performed, thereby calculating the outer orientation element of each photo and the geodetic coordinates of the encryption point.

The basic process includes:

(a). Get the outer orientation element of the image and get the ground coordinate estimate of the encrypted point.

(b). Then write the error equations of the image control points and the encryption points according to the collinear equation, see equation (4).

\[
\begin{align*}
    x - x_0 &= -f \frac{a_1(X_d - X_s) + b_1(Y_d - Y_s) + c_1(Z_d - Z_s)}{a_1(X_d - X_s) + b_1(Y_d - Y_s) + c_1(Z_d - Z_s)} \\
    y - y_0 &= -f \frac{a_2(X_d - X_s) + b_2(Y_d - Y_s) + c_2(Z_d - Z_s)}{a_2(X_d - X_s) + b_2(Y_d - Y_s) + c_2(Z_d - Z_s)} \\
    z - z_0 &= -f \frac{a_3(X_d - X_s) + b_3(Y_d - Y_s) + c_3(Z_d - Z_s)}{a_3(X_d - X_s) + b_3(Y_d - Y_s) + c_3(Z_d - Z_s)}
\end{align*}
\]  

(4)

Because the point coordinates form a nonlinear function, the linearization of the collinear equation can be performed to obtain the partial differential derivative of the outer orientation element of the image and the geodetic coordinates of the encrypted point, see equation (5).

\[
\begin{align*}
    v_x = \frac{\partial X}{\partial X_s} dX_s + \frac{\partial Y}{\partial X_s} dY_s + \frac{\partial Z}{\partial X_s} dZ_s + \frac{\partial \varphi}{\partial X_s} d\varphi + \frac{\partial \omega}{\partial X_s} d\omega + \frac{\partial \kappa}{\partial X_s} d\kappa + \frac{\partial X}{\partial X_s} dX + \frac{\partial X}{\partial Y_s} dY + \frac{\partial X}{\partial Z_s} dZ + x^o - x
\end{align*}
\]
The pixel coordinates are treated as observations, and the error equations of all control points and encryption points are written. See equation (6).

\[
v_x = a_{11}\Delta X_s + a_{12}\Delta Y_s + a_{13}\Delta Z_s + a_{14}\Delta \phi + a_{15}\Delta \omega + a_{16}\Delta \kappa - a_{11}\Delta X - a_{12}\Delta Y - a_{13}\Delta Z - l_x
\]

\[
v_y = a_{21}\Delta X_s + a_{22}\Delta Y_s + a_{23}\Delta Z_s + a_{24}\Delta \phi + a_{25}\Delta \omega + a_{26}\Delta \kappa - a_{21}\Delta X - a_{22}\Delta Y - a_{23}\Delta Z - l_y
\]

The general expression matrix is:

\[
V = \begin{bmatrix} A & B^t \end{bmatrix} \begin{bmatrix} X \\ t \end{bmatrix} - L
\]

The compositional equation is:

\[
\begin{bmatrix} A^t PA & A^t PB \\ B^t PA & B^t PB \end{bmatrix} \begin{bmatrix} X \\ t \end{bmatrix} = \begin{bmatrix} A^t PL \\ B^t PL \end{bmatrix}
\]

4. D product production

4.1. "3D" products

With the development of low-altitude image measurement technology for drones, the post-production work of remote sensing images is also our concern. "3D" products include: DOM, DEM and DSM.

DEM is a ground model that uses a series of ordered matrices to display the height of the ground. If the ground is taken from a certain point as the original point and the values of X and Y are arranged according to certain rules, the DEM can be regarded as one series of Z-range elevation values. DEM can be obtained in many ways: GPS or total station measurement to obtain point data, and then use GIS and other software to generate contour lines and digital elevation models; can use aerial imagery to obtain DEM through full digital photogrammetry technology; generally use TIN for linear Interpolation yields DEM. The resolution of the DEM refers to the length of the smallest unit on the model.

DOM is a map form that transforms into a orthophoto by using a central projection image. Through a series of methods such as radiation transformation, differential correction, merging, and inlaying of
aerial data, map projection, precision, coordinate system, and the same are obtained. The same scale image.

DSM is a simulation of the surface of a ground object that reflects the elevation of the ground on the surface of the plant, the surface of the building, and the trunk. The analysis shows that DEM reflects the elevation of the terrain but there is no data on the surface. The DSM can be processed to delete the information such as houses and vegetation, and DEM can be formed. On the basis of DEM, DSM is added after the elevation of surface information other than the ground is added.

4.2. UAV low-altitude photography digital product production process

The image data of this survey area is measured by the Haida iFLY U3 fixed-wing UAV. Seven routes are laid. The total area of the survey area is 1.51 square kilometers, the ground resolution is 5.36cm/pix, and the photographic altitude is 403m. 151 aerial films, combined with POS data, a total of 150 aerial films participated in data processing. The specific process of data processing is as follows:

(a). Raw data processing.
(b). Import images.

The area of the survey area is 1.51 square kilometers, and the number of images is 151, of which 150 sheets correspond to the POS data. Therefore, a block area is established, and point cloud extraction, photo alignment, and model building are performed.
(c). Align the photo.

Make reference settings before aligning the photos, set the camera accuracy in meters and degrees based on the measurement accuracy, click OK, and the camera position will be marked with its geographic coordinates in the model view. Click the Align Photo button in the menu and set the parameters in the dialog box. See Table 2 for parameter settings.

| Parameter settings | Medium |
|--------------------|--------|
| Paired preselection | General + Reference |
| Key point limit     | 40000  |
| Connection point limit | 4000  |

After the alignment photo is complete, get the sparse point cloud model shown in the model view.

(d). Optimize the alignment of photos.

Align the photo to complete, in order to achieve higher precision in calculating the camera's external and internal parameters and correcting possible distortion, choose to optimize the photo alignment. As shown in Table 3, the camera parameter values selected in the selected optimized alignment.

| Optimize camera parameter values for alignment |
|-----------------------------------------------|
| Types | Frame | F: 7440.21 |
|------|-------|-----------|
| Cx   | -10.0514 | -3.6389 |
| Cy   | 13.0979  | -2.0497 |
| K1   | 0.05507  | 0.00105  |
| K2   | -0.22975 | -0.00165 |
| K3   | 0       | 0         |
| K4   | 0       | 0         |
And get the camera calibration image, and get the camera positioning image. The Z error is represented by the color of the curve, the X and Y errors are represented by the shape of the curve, and the estimated position of the camera is marked with black dots. Look at the coordinate data to get the X, Y, Z error and total error, as shown in Table 4.

Table 4. Camera average calibration error

| Direction | Error value (m) |
|-----------|----------------|
| X         | 0.0050         |
| Y         | 0.0058         |
| XY        | 0.0077         |
| Z         | 3.53           |
| Total error | 3.53           |

(e). Establish a dense point cloud.
(f). Build a grid.
   After the dense point cloud is reconstructed, the polygon mesh model can be generated based on the dense point cloud.
(g). Build textures.
   After the mesh is built, the texture is constructed, that is, the texture. This step is not really needed in the orthophoto export workflow, but the texture model may be checked before exporting, or it may be helpful to accurately place the mark.
(h). Build a DEM.
   The digital elevation model can select a dense point cloud or a mesh model, click to generate a DEM, and set the parameters in the dialog box. The source data is a dense point cloud, and the interpolation can be enabled to obtain the DEM digital product and export it.
(i). Construct an orthophoto map.
   Click on Build Orthographic Image in the menu and set the parameters in the dialog: The surface on which the orthophoto image is generated is DEM. Since the region option button is grayed out and cannot be selected, this orthophoto is done flat and exports the DOM.

5. Conclusion
This thesis mainly studies and analyzes the measurement method of photography industry and the process and principle of 3D product production. The photography field control measurement method mainly studies the image control point layout scheme and its requirements and the image control point joint measurement method, the collective method of using the internal processing software to produce DEM and DOM digital products and the principle of automatic null encryption. It can also be seen through research that DEM and DOM products can be automatically generated by using 3D rapid modeling software. Low-altitude photogrammetry technology is widely used and will have a broader prospect.

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