Analysis of Related Factors of the Precision of Large-scale Surveying of Unmanned Aerial Vehicles (UAV)

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Abstract. With the development of UAV technology, obtaining high-resolution remote sensing images through aerial photography has gradually become popular. This technique has been widely used in various aspects of geomatics. However, state of UAV when flying in the air will be affected by the valley airflow due to small size, light weight, and low flying height in UAV. In addition, the image range of the non-measurement camera equipped with the drone is small, which may lead to a large error in plane and elevation accuracy. For example, it is difficult for the accuracy of drone photogrammetry to meet the survey work of the 1:500 large-scale topographic maps in hills and mountains. Therefore, how to improve the mapping accuracy of the UAV has attract people’s attention at present. In this paper, the source of errors in the 1:500 UAV mapping process is used as an entry point, and the related factors that affect the accuracy of the mapping are analyzed, so as to improve the design of the UAV route.

1. Introduction
At hilly areas with high vegetation coverage and undulating terrain, people need to obtain the 1:500 topographic maps, which means that they have a large workload, long construction period, and high cost. People have always tried to use the UAV aerial survey method for mapping in order to reduce the workload, shorten the construction period, and decrease the cost, but in the 1:500 aerial survey method for topographic map, the mapping accuracy still cannot fully meet the specifications. This article takes the 1: 500 digital line drawing (DLG) production project of Sandu Second Village, Taozhu Street, Zhuji City, Zhejiang Province as an example to compare the accuracy of drone aerial photography mapping, and it analyzes the relevant factors that affect the elevation accuracy. Finally, we put forward some suggestions for improvement.

2. Project Overview
The survey area is hilly terrain with an area of 0.9 km2. The residential area is distributed along the valley. Furthermore, the vegetation is rich and the terrain is undulating. In this area, the lowest part of the survey area is 47.91 meters and the highest part is 105.21 meters with about 60-meters drop. We use the UAV aerial photogrammetry technology, field surveying and supplementary survey to obtain images with a 1:500 digital line drawing (DLG). Finally, the accuracy of the results is obtained and it meets the relevant requirements of Zhejiang Province “1: 500 1: 1000 1: 2000 Digital Topographic Map Surveying and Mapping Specification” (DB33 / T 552-2014).

3. UAV aerial photography system
In this project, the composition of the UAV system we used includes Leica camera (non-measurement camera, 36 million pixels, lens focal length 45.8mm, 1/1000 s exposure time), fixed-wing UAV aerial
photography platform (hand throw), flight control system, differential GNSS, and ground station system. There are 3 operators, which are mission equipment operators (navigators) and flight assistants.

4. The acquisition and processing of UAV aerial photography data

4.1. Technical process
The large-scale mapping of the UAV’s aerial photogrammetry system mainly includes aerial photography, technical preparation, route design, and data processing. The basic process is shown in Figure 1.

![UAV aerial photogrammetry process diagram](image)

4.2. Route design
Based on the operational tasks and low-altitude digital aerial photography specifications, we use the flight control system software to design the parameters of the measurement area. The main content includes the 1: 500 scale of mapping, the design area GSD of 0.05 m, the relative flight height of 350 m, the heading overlap of 80%, and the side overlap of 60%.

4.3. Layout and measurement of image control points
The layout plan is based on the distance of 100m-200m in this photo control point. According to the terrain and features of the survey area, due to the irregular boundaries of the area, we need to add image control points at the bumps.

In addition, SXCORS is utilized for measurement and GNSS RTK for field observation. 107 GNSS three-level points were deployed in order to meet the needs of aerial photography.
4.4. DLG production

Through the camera calibration parameters, we correct the distortion of the original image collected by the drone to eliminate the distortion of the image. In addition, we use 6 external orientation elements provided by the POS data to process the photo. For example, through air-to-air encryption measurement, we perform internal orientation, relative orientation, absolute orientation, and regional network adjustment on the image. Then, based on the results of the air three encryption, dense point cloud data and DOM data are generated. Furthermore, regarding the point cloud data to generate DEM and contour lines, we use CASS to import DOM as a base map to draw DLG, field supplementary survey, mapping. Finally, a product that meets the accuracy requirement of 1: 500 topographic maps is produced.[1-2]

5. Accuracy detection

We use a combination of total station and GNSS RTK in the survey area for data collection at checkpoints in order to verify the feasibility and reliability of UAV aerial survey technology in large-scale surveying. Then, we compare and analyze the spatial coordinate data of the corresponding points on the image, and calculate the difference in the x, y, and h directions. Finally, we use the mid-error calculation formula (1 and 2) to find the mean square error and mean elevation error of the plane points.

\[
M_s = \pm \sqrt{\frac{\sum_{i=1}^{n} \Delta S_i^2}{n}}
\]

(1)

\[
M_h = \pm \sqrt{\frac{\sum_{i=1}^{n} (H_i - \bar{h}_i)^2}{n}}
\]

(2)

In the formula, Ms represents the error in the plane, and Mh represents the error in the elevation. The accuracy statistics are as follows.

(1) Plane accuracy statistics.

The point inspection of the feature points uses the polar coordinate method of the total station, and a total of 477 feature points (obvious building corner points) are checked. According to statistics, the error in the plane is ± 4.3cm; the gross deviation point is 14 (according to a type of feature), and the gross deviation rate is 2.9%.

(2) Elevation accuracy statistics.

The elevation mark point inspection is carried out by using two methods, namely total station and GNSS RTK.

① Total station inspection.

For the elevation inspection of the hardened pavement inside the village and town, a total of 319 elevation points was inspected.

② GNSS RTK inspection.

The internal elevation of various cultivated land was inspected, and a total of 617 elevation points were inspected. According to statistics, the error in elevation is ± 18.8cm; there are 57 gross outliers (of which 41 gross deviation points), and the gross outlier rate is 6.1%.

Regarding the provisions of the Zhejiang Provincial Standard "1: 500 1: 1000 1: 2000 Digital Topographic Map Surveying and Mapping Specification" (DB33 / T 552-2014), the plane position accuracy in the plain area should not be greater than 5 cm, and the elevation accuracy should not be greater than 15 cm. The plane position accuracy meets the specification requirements. Although the elevation accuracy does not meet the requirements of the Zhejiang Standard (DB33 / T 552-2014), it
6. Analysis of main influencing factors of accuracy

6.1. Effect of ground resolution on plane accuracy
The accuracy of space point plane coordinates depends on the measurement accuracy of image point coordinates. The plane coordinate accuracy of the space point obtained from the front intersection of the stereo pair is

\[ \Delta x = \delta \times \frac{H}{f} \]  

(3)

If the measurement accuracy (\( \delta \)) of the image point is (\( k \) ) pixels, then the plane accuracy can be obtained as

\[ \Delta x = \frac{GSD}{k} \]  

(4)

The ground resolution is the ground size corresponding to the smallest image point that can be distinguished from the background. It can be seen that the smaller the ground size, the higher the resolution. The relationship is as follows:

\[ GSD = \frac{H \times \alpha}{f} \]  

(5)

In the formula:
- \( GSD \) is the ground resolution (m);
- \( H \) is the height of photography (m);
- \( f \) is the focal length of the photographic lens (mm);
- \( \alpha \) is the pixel size (mm).

The relationship between the ground resolution of the image and the altitude is as follows.

When the altitude is high, the resolution is low. However, when the altitude is low, the ground resolution of the image is relatively high. Moreover, after the aerial camera is determined, the focal length (\( f \)) and the pixel size (\( \alpha \)) are fixed values, and the size of the GSD depends on the setting of the photographic aerial height \( H \). In addition, the survey area of this project is a hilly area. In the design of the altitude, the area below the average elevation is fully considered to meet the ground resolution requirements, and the designed altitude value is reasonable. Finally, combined with the accuracy test results of this project, it can be seen that the design value of the aerial altitude conforms to the topography of the survey area, and the acquired image GSD meets the requirements. The accuracy of the spatial point plane is high, which meets the requirements of relevant specifications.[3]

6.2. The influence of base height ratio on elevation accuracy
The base height ratio is the ratio between the length of the photographic baseline and the height of the camera station. It determines the degree of overlap of adjacent images in the heading. The relationship between them is that the greater the base-height ratio, the smaller the heading overlap, and vice versa. Furthermore, the greater the overlap of the image course, the lower the accuracy of the stereoscopic
observation and elevation measurement. For example, a large degree of overlap indicates that the two adjacent images form a stereo model when the stereo pair is formed, and the vertical scale is not obvious. This means that the stereoscopic effect is poor, which affects the observation. The relationship is as follows:

\[ G = \frac{B}{H} \]  

In the formula:
- \( G \) is the base height ratio;
- \( H \) is the height of photography;
- \( B \) is the baseline of photography.

The base height ratio reflects the intersection angle of two adjacent camera stations to the ground point. When the measurement accuracy is fixed, the base-height ratio will affect the elevation accuracy during stereo collection because the intersection angle of the UAV is small, as shown in Figure 2. We assume that the measurement error of the right image is \( \delta \) and the resulting elevation error is \( \Delta h \). Since \( f \) is very small, we can consider as \( H + f \approx H \), which can be obtained according to the triangle similarity principle.

\[ \Delta h = \frac{\Delta x \times H}{B \times f} \times G \times \delta \]  

The photography baseline is multi-site photography, which is generally controlled by the exposure time interval. After the camera is determined, the photographic baseline \( B \), the focal length \( f \), and the measurement error \( \delta \) are considered to be fixed values, and the measurement error \( \delta \) is generally half or one pixel. In addition, the elevation error \( \Delta h \) is inversely proportional to the base height ratio \( G \), while it is proportional to the aviation height \( H \). Also, the base height ratio \( G \) will decrease as the image overlap increases, so when the altitude \( H \) is determined, the elevation error \( \Delta h \) is
proportional to the overlap. It can be seen from the above formula that the elevation accuracy mainly depends on the base height ratio. The greater the base height ratio, the better the elevation accuracy. The terrain of the project area has high relief and significant elevation changes. Due to the limitation of the focal length of the camera, the resolution difference between images is large, which could affect the efficiency of data processing and the elevation accuracy of the topographic map. In addition, according to the topography of the survey area, the relative altitude value is controlled within a certain range, which has a significant effect on improving the elevation accuracy. Therefore, when designing the route, we should fully consider the direction of the UAV heading.

7. Conclusion
From the accuracy analysis results, we can see:

1. The plane accuracy of UAV aerial photography is mainly determined by the resolution of the photo. For example, the higher the resolution and the better the image quality, the more accurate the interpretation and the smaller the error. Therefore, if we need to improve the mapping accuracy, the ground resolution and image quality of the photo have to first be enhanced, and the resolution depends on whether the design of the aerial height value is reasonable.

2. The accuracy of drone aerial photography elevation is mainly determined by the base-height ratio. In the course of route design, operators often only pay attention to the setting of the altitude and shape of the survey area, thus ignoring the key role of direction. Furthermore, in the setting process, the direction should be consistent with the contour line. This means that the photographic baseline should be parallel to the contour, so as to reduce the impact of the abrupt changes in altitude caused by terrain fluctuations on the overlap of the heading of the photos. This can keep the heading overlap and the design value within a certain range, thereby improving the elevation accuracy.[4-5]

3. For irregularly shaped survey areas (such as hills or mountains), on the premise of guaranteeing the voyage, we should try to use framing routes. A reasonable route can greatly improve the accuracy of aerial surveying and mapping.

4. Due to the over-limit of elevation caused by vegetation cover and ground obstruction, we must carry out field supplementary survey to correct elevation annotation points to improve accuracy, which can meet the requirements of the specification.

In this article, the factors that affect the plane and elevation accuracy are simply analyzed by us. We do not discuss the effect of the heading angle method on elevation accuracy in detailed, and we do not quantify the improvement of elevation accuracy by this method. These works will continue to be analyzed in future project.

References
[1] Surveying and mapping circulars. Bi, K, Li, Yc, Ding, Xb. (2015) Current status and development trend of aerial photography of light and small UAV.,(3):27-31.
[2] Surveying and mapping circulars. Ding, Yx, Zou, Ix, Zhu, Xk. (2018) : 500 Key Technology and Application Research of Large Scale Mapping for UAV., (S1) : 154-157.
[3] Fujian Geology. Chensk. (2017) Application of UAV aerial photography in mapping large scale topographic map in hilly area., (03) : 76-81.
[4] Science and Technology Innovation Bulletin. Lu Jc. Application of UAV tilt photography in surveying and mapping field., 14 (34) : 94-95.
[5] Surveying and mapping circulars. Sun Yy. (2016) Application of Virtual Measurement in Surveying and Mapping of UAV., (07):148-149.