Research on UAV Large Scale Mapping and its elevation fitting

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Abstract. Due to the influence of the external environment and the limitation of data processing methods, the accuracy of the unmanned aerial vehicle (UAV) aerial photogrammetry needs further studies in the aspect of mapping large-scale topographic maps. In order to verify whether the measurement accuracy of the UAV aerial photography system meets the requirements of large-scale topographic maps, this paper conducts an accuracy test on a topographic map, using the surface fitting model, the plane fitting model, quadratic surface fitting and polyhedral function method fitting based on field measured data. The fitting of four models to the elevation points by the combined polyhedral function method. The elevation difference between the flat area and the mountain area was corrected, and the elevation accuracy of the four methods was compared. This paper shows that in flat areas the elevation accuracy of the surface fitting model is better than the plane fitting model, quadratic surface fitting, and polyhedral function method fitting. In the mountainous region, the elevation accuracy of the quadratic surface fitting model is better than that of the plane fitting model, quadratic surface fitting, and polyhedral function method fitting.

1. Introduction

With the rapid development of unmanned aerial vehicle (UAV) technology, the application fields of UAV are extremely wide. UAV have a far-reaching impact in the fields of urban planning, digital cities, national emergency disaster relief, geographic and national conditions monitoring, power engineering [1-3], and engineering surveys. Due to the advantages of high efficiency, low investment cost and flexible maneuverability, drones can quickly acquire high-resolution images over the measurement area in small or complex areas. According to mission requirements, modern UAV systems can obtain image data with different resolutions. After the images are reprocessed, digital spatial geographic information products that serve different users can be produced, such as: digital orthophoto map (DOM), digital elevation model (DEM), digital line drawing (DLG), etc. Modern UAVs are favored in related industries because of their unique advantages and uniqueness, especially the unmanned aerial photogrammetry technology widely serves various fields [4-6].

Using traditional methods to survey topographic maps, the use of instruments is more complicated, the task of field surveyors is large, and the working environment is very harsh. Using Real Time Kinematic (RTK) mapping, the satellite signal is unstable during the mapping, and the radio station signal is easily interrupted, affecting work efficiency. Due to the traditional technical methods of surveying and mapping topographic maps, they have the disadvantages of low efficiency, time-consuming drawing, and high economic costs. They need to go to the field to perform operations, especially in complex terrain areas, Such as mountainous areas, hilly areas, jungles, desert areas, frequent geological disaster areas and other areas, prone to personal safety accidents. Using satellite
remote sensing photogrammetry, the surveying and mapping of topographic maps will be restricted by natural conditions such as weather and landform.

In addition, photogrammetry system is to use drone equipped with sensor equipment, such as digital camera, etc., to perform aerial photography in the work area to obtain image data, and to process the image data to obtain the digital orthophoto image usually used (Digital Ortho Map, DOM), Digital Line Graphic (DLG), digital topographic map, digital 3D model and other products. Compared with traditional aerial photography systems: the application of airspace is relatively easy; the flight site is less limited [7] and no airport is required; the cloud cover is less restrictive; it is a low-altitude flight and can obtain higher resolution images; easy to operate It has high operational efficiency and low investment, which effectively fills the defects of conventional aerial survey methods [8]. It has great development advantages in acquiring basic data of spatial geographic information, especially in digital topographic map surveying [9].

Although the ground point coordinate accuracy obtained by the captured drone image data is higher, the elevation accuracy obtained is lower. And the elevation value in the three-dimensional coordinates obtained by the drone photogrammetry is based on the height of the WGS-84 reference ellipsoid, which has no practical physical significance in the process of use. It is necessary to convert the geo-high data obtained by drone photogrammetry into commonly used normal elevation (elevation based on a geoid), in this conversion process involves elevation fitting, this paper uses four elevation fitting methods to improve the accuracy of elevation in the area, but also compares the results of elevation fitting of the flat and mountainous areas, respectively, to obtain which method is suitable for flat areas and mountain areas.

2. Research methods

2.1. Plane fitting model method
By establishing a mathematical model of plane fitting and simulating the difference in elevation, using the discrepancy between the measured value of the field elevation and the three-dimensional measurement value of the checkpoint, the least square method is used for fitting to make the plane fit at the elevation checkpoint The difference between the correction value and the actual value is the smallest, used to improve the accuracy of the elevation of the measurement area.

The expression of the plane fitting model method is as follows:

\[ \zeta = a_0 + a_1x_i + a_2y_i \]  

\[ (1) \]

There are 3 parameters to be determined in the above formula. At least 3 checkpoints must be selected from the height checkpoints and calculated by the column equation, then the error equation is:

\[ v_i = a_0 + a_1x_i + a_2y_i - \zeta \]  

\[ (2) \]

Among them, select an elevation checkpoint, you can list an error equation, rewrite the error equation into a matrix form as follows:

\[ V = AX - \zeta \]  

\[ (3) \]

Using the principle of least squares, the parameters \( a_0 \), \( a_1 \), and \( a_2 \) are calculated.

\[ A = (X^TX)^{-1}(X^Tz) \]  

\[ (4) \]

The calculated undetermined parameter value is substituted into the formula to calculate the plane fitting function, and then the elevation difference of the checkpoint is determined.

2.2. Surface fitting model method
The surface fitting method is that elevation points are distributed in a certain area, the mathematical surface can be selected to fit the quasi geoid of the area, and the appropriate mathematical model can be constructed to calculate the height anomaly value in the region, and finally the normal height can be obtained.
The elevation correction value is \( \xi \), \( f(x, y) \) is the fitting trend surface of \( \xi \) with respect to \((x, y)\), and \( \tau \) is the fitting error, then

\[
\xi = f(x, y) + \tau \quad (5)
\]

\[
f(x, y) = a_0 + a_1x + a_2y + a_3xy + a_4x^2, \quad \xi = \begin{bmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \\ \xi_4 \\ \xi_5 \end{bmatrix}, \quad C = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}^T, \quad \tau = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \end{bmatrix},
\]

\[
\xi = CX + \tau \quad (6)
\]

\[
2.3. \textit{Quadratic surface fitting model method}
\]

The quadratic surface fitting model method has relatively high requirements on the number and position of known points. Generally, at least 6 known points are required, and they are evenly distributed in the measurement area. The expression of the quadratic surface fitting model is as follows:

\[
\zeta = a_0 + a_1x_i + a_2y_i + a_3x_i^2 + a_4y_i^2 + a_5x_iy_i \quad (8)
\]

Using the principle of least squares, the parameters \( a_0, a_1, \ldots, a_5 \) are calculated.

\[
A = \left( X^T X \right)^{-1} \left( X^T \zeta \right) \quad (9)
\]

\[
2.4. \textit{Polyhedral function method}
\]

The basic principle of the polyhedral function method is to use surface fitting to superimpose a smooth surface, and then perform fitting application. The expression of the multifaceted function method is:

\[
\zeta = \sum_{i=1}^{k} C_i Q(x, y, x_i, y_i) \quad (10)
\]

The specific solution process is:

\[
\zeta = AX \quad (11)
\]

Available from above:

\[
A = X^{-1} \zeta \quad (12)
\]

Therefore, the calculated elevation difference is:

\[
\zeta_r = AX_r = X_r X^{-1} \zeta \quad (13)
\]

\[
3. \textit{The research and analysis of the elevation accuracy of the large scale mapping based on the elevation fitting model}
\]

\[
3.1. \textit{Research area}
\]

This aerial survey takes (a) the flat area Guilin University of Technology Bowen School of Management Yanshan campus and (b) mountain area Linchuan County Lingtian Town Yongzheng Village Zizitang Village Test as an example (Figure 1). The flat area is located in Yanshan District, Guilin City, which is located in the northeast of Guangxi Zhuang Autonomous Region, south of Guilin City, east of Lingchuan County, west of Lingui District, south of Yangshuo County, north of Xiangshan District and Qixing District, with the longitude 110°29′, the latitude 25°06′. The mountainous area is located in the north of Guilin City in the Guangxi Zhuang Autonomous Region and the east of Lingchuan County, with the longitude 110°30′, the latitude 25°06′. The two research areas are shown in Figure 1 below.
3.2. Production of digital orthophoto map and digital topographic map

3.2.1. Production of digital orthophoto map. The digital orthophoto map (DOM) has the advantages of high accuracy, large amount of information, substantial content, very fast production and strong presence. After aerial triangulation and processing of business data, this paper can obtain the DOM, as shown in Figure 2.

3.2.2. Production of digital topographic map. After processing the internal data, we need to collect the terrain feature data, and make a digital line drawing (DLG). Strictly follow the "Low Altitude" The relevant requirements in the Digital Photogrammetry Field Code shall ensure the quality of the drawing [10-11]. Finally, according to the data format requirements of CASS mapping software, the digital line drawing (DLG) is edited into the required digital topographic map [12-13]. As shown in Figure 3.

In the process of data processing, the checkpoints with obvious characteristics and easy to be interpreted are randomly selected. In this paper, 70 points with obvious characteristics are randomly selected in the flat area and the mountainous area. Check the plane point position error and elevation accuracy by comparing the coordinates on the map of the inspection point with the measured coordinates collected by RTK. Due to the large number of selected checkpoint data, only the checkpoint information of the area is shown in Table 1 and Table 2.
Figure 3. (a) Digital topographic map of Yanshan campus of Bowen School of Management, Guilin University of Technology, flat area; (b) Digital topographic map of Zi road Village, Yongzheng Village, Lingtian Town, Linchuan County, mountain area.

Table 1. Topographic map point data of survey area.

| X1       | Y1       | H1       | X2       | Y2       | H2       | Elevation difference |
|----------|----------|----------|----------|----------|----------|----------------------|
| JC01 2773673.669 | 428265.617  | 103.8223 | 2773673.623 | 428265.668 | 122.8555 | 19.0332 |
| JC02 2773664.707 | 428321.657  | 104.3714 | 2773664.839 | 428321.700 | 123.4018 | 19.0304 |
| JC34 2773596.177 | 428404.533  | 103.7409 | 2773596.153 | 428404.527 | 122.7844 | 19.0435 |
| JC35 2773608.579 | 428317.599  | 103.2919 | 2773608.539 | 428317.581 | 122.3223 | 19.0304 |
| PC01 2806490.621 | 452594.369  | 614.1107 | 2806490.726 | 452594.422 | 634.1919 | 20.0812 |
| PC02 2806202.105 | 452800.267  | 616.4219 | 2806202.048 | 452800.192 | 636.5021 | 20.0802 |
| PC34 2806372.732 | 452439.076  | 620.3615 | 2806372.784 | 452439.129 | 640.4377 | 20.0762 |
| PC35 2806366.956 | 452499.604  | 618.2928 | 2806366.863 | 452499.695 | 638.7340 | 20.0812 |

Note: X1, Y1, H1 are the coordinate and elevation of the measured point on the graph; X2, Y2, H2 are the coordinate and elevation of the measured point by RTK; the point whose name starts with JC is the point of the flat area, and the point whose name starts with PC is For the points in the mountain area, the following point names are consistent with the point names shown in Table 1.

Table 2. Accuracy statistics table of checkpoints of topographic map in survey area.

| ΔX    | ΔY    | ΔXY   | ΔX    | ΔY    | ΔXY   |
|-------|-------|-------|-------|-------|-------|
| JC01 -0.046 | 0.051 | 0.069 | JC02 0.132 | 0.043 | 0.139 |
| JC02 |       |       | PC01 | 0.105 | 0.053 | 0.118 |
|       |       |       | JC34 | -0.024 | -0.006 | 0.025 |
| JC34 | -0.04 | -0.018 | PC34 | 0.052 | 0.053 | 0.074 |
| JC35 | -0.04 | -0.018 | PC35 | -0.093 | 0.091 | 0.130 |

According to the data of ΔX, ΔY and ΔXY in the above table, and data in the above table, the midpoint error of the checkpoint can be calculated according to the medium error formula, see formula 14:

\[ M_{ΔY} = \sqrt{\frac{\sum(ΔXY)^2}{n-1}} \]  

Where n is the number of checkpoints.

According to the accuracy statistics of the inspection points in the survey area, the error in the location of the inspection points in the flat area is 0.108m. The point error of the check point of the mountain area is 0.202m.
According to the data in Table 1 and Table 2 and the above analysis results, it can be seen that the accuracy of the topographic map obtained from the image processing of the aerial survey area obtained by the aerial survey system of this drone (the error in the point of the flat area checkpoint is 0.108m, The error in the position of the checkpoint in the mountain area is 0.202m) can meet the accuracy requirements of 1:500 scale digital topographic map mapping. The relevant specification requirements are shown in Table 3 below. Although it meets the requirements, the elevation accuracy is not high. In the future work, we must strengthen the working environment and improve the quality of the original data.

| Mapping scale | Flat land, hills | Mountain, high mountain |
|---------------|------------------|-------------------------|
| 1:500         | 0.4              | 0.55                    |
| 1:1000        | 0.8              | 1.1                     |
| 1:2000        | 1.75             | 2.5                     |

3.3. Contrast study and analysis of elevation accuracy of elevation fitting model for flat area and mountain area

Converting the geodetic height data obtained by drone photogrammetry to the commonly used normal height. In this conversion process, anomalous elevation fitting is involved. In this paper, four elevation fitting methods are used to improve the accuracy of the elevation in the area. This method fits the elevation fitting results of the flat area and the mountain area respectively. The purpose of this article is to find out which method is suitable for flat areas and mountainous areas. To this end, this section counts the elevation accuracy line chart and elevation fitting method accuracy box plot of 40 points in flat and mountain areas by using four methods (as shown in Figure 4 below).

Figure 4. (a) Accuracy line graph of 4 elevation fitting methods in flat areas; (b) Accuracy line graph of 4 elevation fitting methods in flat areas; (c) Accuracy line graph of 4 elevation fitting methods in mountain areas; (d) Accuracy box plot of 4 kinds of elevation fitting methods in mountain area.
Figure 4 shows the fitting of 40 elevations in flat areas and mountainous areas using 4 elevation fitting methods in this paper. Among them, we can get a certain improvement in elevation accuracy by using 4 methods. The red dotted line in the figure is the elevation difference of 20 points in the flat area and the mountain area, and the blue dotted line indicates the horizontal line with zero error. The two dashed red lines and the dashed blue lines assist the comparison of the four methods. By comparing the results of the four elevation fitting methods, we find that the red polyline in Figure 4 (a) is obtained by the quadratic surface fitting model. The difference in elevation, the black broken line is the difference in elevation obtained by the plane fitting model. By comparing the error graphs of these two sets of lines, we can get the minimum error of the quadratic surface fitting model for the height fitting of points JC01-JC04, JC08-JC09, JC11, JC15 and JC17, and the opposite result A bit JC05-JC07, JC10, JC12-JC14, JC16 and JC18-JC20. However, the error of height fitting by the plane fitting model is the smallest in the region. In the same analysis method, in Figure 4 (a-2), the red polyline is the elevation difference obtained by the multifaceted function model, and the black polyline is the elevation difference obtained by the surface fitting model. Through the comparison of these two sets of polylines, we can get that the multi-faceted function model has the smallest error in the elevation fitting of points JC01-JC03, JC07-JC11, and JC16-JC17, and the opposite results are somewhat JC04-JC06, JC12-JC15 And JC19-JC20. However, the surface fitting model uses the surface fitting model to obtain the height fitting error is the smallest. For the problem of large elevation error of these fittings, this paper counts the accuracy box plots of the four elevation fitting methods in the flat area (as shown in Figure 4(b)). The blue dotted line represents the horizontal line with zero error. By analyzing the distance between the blue solid line and the blue dotted line of the box plot, compared with the other three methods, we can get the flat area using the surface fitting model to obtain the elevation error. The blue dotted line is relatively close, indicating that the surface fitting model used in this paper is beneficial to improve the accuracy of elevation.

Using the same analysis method to analyze the mountain area (as shown in Figure 4 (c-1)), we can get the quadratic surface fitting model for points JC02-JC05, points JC08, points JC12-JC15, points JC17 and JC18 and points The error of JC20 elevation fitting is the smallest, the opposite result is a bit JC1, JC06-JC07, JC09-JC10, JC11, JC16 and JC19. However, the error of the height fitting obtained by using the plane fitting model for the points in these areas is the smallest. In the same analysis method, in Figure 4 (c-2), the red polyline is the elevation difference obtained by the polyhedral function model, and the black polyline is the elevation difference obtained by the surface fitting model. Through the comparison of these two sets of polylines, we can obtain that the multi-faceted function model has the smallest error in the elevation fitting of points JC02-JC06, JC10-JC12, and JC19-JC20, and the opposite result is a bit of JC01, JC07-JC09 and JC13-JC18. However, the surface fitting model uses the surface fitting model to obtain the height fitting error is the smallest. For the problem of large elevation error of these fittings, this paper counts the accuracy box plots of the four elevation fitting methods in the flat area (as shown in Figure 4(d)). The blue dotted line represents the horizontal line with zero error. By analyzing the distance between the blue solid line and the blue dotted line of the box plot, compared with the other three methods, we can get the mountain area using the quadratic surface fitting model to obtain the elevation error It is closer to the dashed blue line, indicating that the quadratic surface fitting model used in this paper is conducive to improving the accuracy of elevation.

Through the above analysis, the elevation accuracy of the surface fitting model in the flat area is better than that of the planar fitting model, quadratic surface fitting and polyhedral function method. In the mountainous region, the height accuracy of the quadratic surface fitting model is better than that of the plane fitting model, surface fitting model and polyhedral function method. Of course, the selection of fixed checkpoints will also have a certain impact on the accuracy of the fitting results.

4. Conclusion
In view of the low elevation accuracy of UAV aerial survey topographic maps, this paper adopts four methods of establishing plane fitting model, surface fitting, quadric surface fitting and polyhedral function method for elevation fitting. The elevation correction results of the four methods are applied
in the survey area. The research results Table: 1) In a small area and relatively flat terrain, the overall elevation accuracy of the topographic map has been improved to a certain extent. 2) Through the fitting test of the elevation of the test area, in the case of consistent selection of fixed checkpoints, four methods of plane fitting model, surface fitting, quadric surface fitting and polyhedral function method are used in the flat area to point JC01-point JC20 elevation abnormality is fitted, and the elevation errors of these 20 points are obtained. Comparing the correction accuracy of these four methods, this paper can obtain that the elevation accuracy of the surface fitting model is better than the plane fitting model. Height accuracy of quadratic surface fitting and polyhedral function fitting. 3) In the mountainous area, four methods of plane fitting model, surface fitting, quadric surface fitting and polyhedral function method are used to fit the point PC01-point PC20 elevation difference, and the results of these methods are compared and analyzed. The elevation accuracy of subsurface fitting model is better than that of plane fitting model, surface fitting model and polyhedral function method. Of course, the selection of fixed checkpoints will also have a certain impact on the accuracy of the fitting results.

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