Plane Accuracy of Aerophotogrammetry without Image Control Points of DJI PHANTOM 4 RTK UAV

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Abstract. The small unmanned aerial vehicles (UAVs) have good operability, low cost and high production efficiency in the low-altitude aerophotogrammetry. In this paper, the checkpoint coordinate data of low-altitude aerophotogrammetry from DJI PHANTOM 4 RTK UAV in the image-free controlled model are compared with the measured data of GNSS RTK. The results show that the maximum errors of the plane coordinates of checkpoints extracted by UAV were 0.067 m and 0.045 m in X-direction and Y-direction respectively and the plane mean square error (PMSE) was ± 0.051 m, which meet the rules of the national standard and industrial standard. Therefore, the low-altitude aerophotogrammetry of DJI PHANTOM 4 RTK UAV without the image control points can be effectively applied to large-scale surveying and mapping in small areas.

1. Introduction

Compared with the traditional methods of geomatics, the low-altitude aerophotogrammetry technology of UAV has the advantages of portability, low cost and high efficiency. In recent years, the low-altitude aerophotogrammetry of UAV has developed rapidly with the miniaturization and integration of high-accuracy GNSS, which can be easily mounted on small UAV. Meanwhile, since the accuracy of hardware equipment has been greatly improved, the image-free controlled technology has been widely and efficiently applied in surveying and mapping. DJI PHANTOM 4 RTK UAV, a small kind with four rotors, is equipped with centimeter-level positioning system and high-performance program, which bring great convenience to surveying and mapping mission, such as obviating the image control point, simplifying the operation process and improving the work efficiency. Moreover, the collected data can be directly compatible with the operation software like UAV-PPK and Context Capture etc. These characteristics make DJI PHANTOM 4 RTK UAV widely applied to geological survey, topographic mapping, environmental monitoring and other fields. DJI Company described that the mapping accuracy of the DJI PHANTOM 4 RTK UAV met the requirements of Specifications for Aerophotogrammetric Office Operation of 1: 500 1: 1000 1: 2000 Topographic Map (GB/T 7930-2008). In this paper, based the comparisons of checkpoints coordinate data from the low-altitude aerophotogrammetry of DJI PHANTOM 4 RTK UAV without image control points and the measurement of GNSS RTK, respectively, the accuracy and reliability of large-scale
aerophotogrammetry of small UAV are verified, which can provide referential experiences for high-accuracy surveying and mapping of UAV.

2. Test region
A seaside park, with some artificial facilities including vegetation, walkways, stairs, hardened pavements and simple buildings, in Qingdao, Shandong Province is selected as the test region. It is open to the public for free. The terrain of the park is relatively flat. The area for aerophotogrammetry is about 0.1 km² in the park. The details are shown in Figure 1.

Figure 1 The panoramic photograph of the test region

3. Data Acquisition

3.1. Plane coordinate data of the checkpoints from GNSS RTK
Considering the principle of uniform layout and the actual aerophotogrammetry area, six checkpoints were homogeneously and conspicuously deployed (Figure 2). There was no cover near the checkpoints, and they could be identified in the aerial photos. The pattern of the checkpoints is a red and black circle with a radius of 25 cm (Figure 2). GNSS RTK produced by Trimble Inc. was used to measure the plane coordinate information of the six checkpoints under the SDCORS network and CGCS2000. Each checkpoint was observed for five times independently. The average of five observations was taken as the true value. The scene of coordinate measurement of six checkpoints are shown in Figure 3. All the equipments are in the valid period of verification and applicable to this mission.

Figure 2 The location of the checkpoints deployment (left one, red triangles) and pattern of checkpoints (right one).
Figure 3  The scene of coordinate measurement of six checkpoints

3.2. Aerial image data from PHANTOM 4 UAV

The DJI PHANTOM 4 RTK UAV is equipped with a 20-megapixel digital camera, of which lens focal length is 8.8 mm and pixel size is 0.00241 mm. The main parameters of UAV are shown in Table 1. In order to ensure the quality of the aerial photos, the flight was carried out in a sunny afternoon without wind and fog. The heading overlap and side overlap rate were set to 80% and 60% in DJI GS RTK APP, respectively. According to the inputted take-off point, flight altitude and other parameters, the APP automatically calculated and generated the flight route of this mission (Figure 4). The flight lasted about nine minutes, and 226 original images were obtained. The formula for calculating the ground sample distance (GSD) is shown as follow:

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

\(1\)

Where \(H\) (flight altitude) is 100 m, \(f\) is 8.8 mm and \(\alpha\) is 0.00241 mm. The GSD of the aerial images is 2.74 cm, meeting the requirements of the Specifications for Low-altitude Digital Aerial Photography (CH/Z 3005-2010). In addition, the photography of the test region was complete and the obtained images were clear and uniform. These all meet the requirements of Specifications for Office Operation of Low-altitude Digital Aerophotogrammetry (CH/Z 3003-2010). Thereby, there is no need for supplementary mission.

Table 1  Some parameters of DJI PHANTOM 4 RTK UAV

| Item                          | Parameter value          |
|-------------------------------|--------------------------|
| UAV weight                    | 1 391 g                  |
| battery life                  | ~30 minutes              |
| camera pixels                 | 20-megapixel             |
| lens focal length             | 8.8 mm                   |
| pixel size                    | 0.00241 mm               |
| vertical positioning accuracy | 1.5 cm + 1 ppm (RMS)     |
| horizontal positioning accuracy| 1 cm + 1 ppm (RMS)       |
4. Processing and analysis of aerophotogrammetry data

4.1. Data processing

Metashape Software was used to processing the collected aerial photos for generating the Digital Orthophoto Map (DOM). First, 226 original images were aligned based on latitude and longitude location information, feature points and camera parameters. After that, a set of sparse point cloud was formed. And then, digital elevation model (DEM) and DOM were generated in turn. The DOM was outputted in TIF format.
4.2. Plane accuracy analysis

Based on the DOM of test region from DJI PHANTOM 4 RTK UAV in the image-free controlled mode, the plane coordinate of the six checkpoints were extracted by ArcGIS Software. Comparing the plane coordinates from UAV and the corresponding true values from the GNSS RTK, the results showed the error ranged from 0.002 m to 0.067 m in the X direction and from 0.018 m to 0.045 m in the Y direction, respectively (Table 2). The plane mean square error (PMSE) was ± 0.051 m, which was in line with Specifications for Aerophotogrammetric Office Operation of 1:500 1:1 000 1:2 000 Topographic Map (GB/T 7930-2008) and Specifications for Office Operation of Low-altitude Digital Aerophotogrammetry (CH/Z 3003-2010). The terrain situation, environmental factor, method of data process and extraction of checkpoint coordinate could cause the system errors, which should be avoided as much as possible in both of field work and office operation.

Table 2  Plane accuracy of checkpoints

| Checkpoint Number | X/ m from GNSS RTK | Y/ m from GNSS RTK | X/ m from UAV | Y/ m from UAV | ΔX/ m | ΔY/ m | PMSE/ m |
|-------------------|--------------------|--------------------|--------------|--------------|-------|-------|---------|
| 1                 | 40*****.539        | 56****.871         | 40*****.606  | 56****.895   | 0.067 | 0.024 | ± 0.051 |
| 2                 | 40*****.389        | 56****.798         | 40*****.403  | 56****.843   | 0.014 | 0.045 |         |
| 3                 | 40*****.134        | 56****.984         | 40*****.145  | 56****.023   | 0.011 | 0.038 |         |
| 4                 | 40*****.056        | 56****.294         | 40*****.058  | 56****.276   | 0.002 | - 0.018 |         |
| 5                 | 40*****.433        | 56****.786         | 40*****.383  | 56****.749   | - 0.050 | - 0.037 |         |
| 6                 | 40*****.378        | 56****.519         | 40*****.347  | 56****.557   | - 0.030 | 0.038 |         |

ΔX is the error of plane coordinate in the X direction. ΔY is the error of plane coordinate in the Y direction.

4.3. Plane accuracy of different RTK UAVs

In addition to DJI PHANTOM 4 RTK UAV, there are some kinds of RTK UAVs which can be used to conduct 1: 500 and 1: 1 000 topographic maps efficiently. According to the requirements of the missions, the different numbers of image control points can be selected. The plane accuracy of several popular RTK UAVs is listed in Table 3. It can be seen that the PMSEs of these RTK UAVs are less than ± 0.2 m, meeting the requirements of the national standard and industrial standard.

Table 3  Plane accuracy of different RTK UAVs

| Type               | PMSE/ m     | References |
|--------------------|-------------|------------|
| DJI PHANTOM 4 RTK UAV | ± 0.051     | this paper |
| DJI MATRICE 210 RTK UAV | ~ ± 0.06    | reference 8 |
| TRIMBLE UX-5       | ± 0.13, ± 0.14 | reference 9 |
| HUAYAO P310        | ± 0.17, ± 0.10 | reference 10 |

5. Conclusion

The plane coordinate information of the six checkpoints extracted from the low-altitude aerophotogrammetry data of DJI PHANTOM 4 RTK UAV in the image-free controlled model were compared with those measured by GNSS RTK. The results showed that the maximum errors of the plane coordinates of checkpoints from UAV were 0.067 m and 0.045 m in X direction and Y direction, respectively. The PMSE was ± 0.051 m, meeting the requirements of the national standard and industrial standard.

The low-altitude aerophotogrammetry of DJI PHANTOM 4 RTK UAV based on the image-free controlled technology can be effectively applied to large-scale surveying and mapping in small areas. However, it is subject to weather, endurance and other factors. With the improvement of endurance, flight accuracy and stability, development of supporting software, the low-altitude aerophotogrammetry of UAV will be continuously expanded in more fields.
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