Large-scale mapping using UAV-based oblique photogrammetry

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Abstract

Tilt photogrammetry technology breaks through the limitation of orthorectified images that can only be captured from a vertical angle, by carrying multiple sensors to capture images from different angles such as one vertical and multiple tilts. This can obtain higher resolution, larger field of view angle, and more detailed ground information data than traditional methods. In the image acquisition stage, onboard sensors record parameters such as altitude, speed, heading, lateral overlap, and coordinates, and embed geographic image information to enable real-time recording of aircraft attitude parameters with the image data. In the processing of this study, oblique photogrammetry technology was used to obtain image data of the measured area, and GNSS-RTK and IMU systems were used to assist in obtaining external azimuth elements. Meanwhile, the experiment completed route planning, drone assembly, parameter setting, image control scheme design, and measurement. Complete the steps including photo quality inspection, image control point selection and editing, and aerial triangulation calculation. Finally, this study completed the 3D model reconstruction of the measurement area, and 4D product production includes DLG, DOM, and DEM. The quantitative accuracy analysis and visual representation confirmed that the research result meets the requirements of 1:500 scale mapping, and the 3D model can accurately express the information of physical objects.

1. Introduction

The research background of large-scale mapping through UAV oblique photogrammetry mainly involves the limitations of traditional photogrammetry technology and the advantages of UAV oblique photogrammetry technology.

Traditional photogrammetry technology primarily relies on photography from vertical angles, which has limitations in comprehensively and accurately reflecting the objective conditions of the ground surface (Aicardi et al. 2016). Additionally, for large-scale topographic mapping, traditional photogrammetry often necessitates a large number of ground control points, which not only increases the workload but also limits the accuracy and efficiency of the measurement. The emergence of drone oblique photogrammetry technology has overcome the limitations of traditional photogrammetry (Bemis et al. 2014). By equipping drones with multi-lens oblique cameras, they can capture images from different angles, quickly and efficiently acquiring surface data (Stefanik et al. 2011). This technology not only accurately reflects the objective conditions of the ground surface but also, due to its ultra-low-altitude aerial photography, captures image data with ultra-high resolution, making it highly suitable for large-scale topographic mapping.

Drone oblique photogrammetry technology also boasts advantages such as high automation, labor and material savings, and short cycle times (Niethammer et al. 2012). By equipping drones with non-metric cameras for topographic mapping, coupled with real-scene 3D modeling technology, orthorectified image results can be obtained, ensuring a controllable mapping cycle and timeliness (Frahm et al. 2010). This technology significantly enhances the efficiency of large-scale mapping work, providing faster and more accurate surveying and mapping services for various industries.

The large-scale mapping of UAV oblique photogrammetry is primarily aimed at addressing the limitations of traditional photogrammetry technology, leveraging the advantages of UAV oblique photogrammetry technology, and enhancing the accuracy and efficiency of large-scale topographic mapping (Colomina et al. 2014). As UAV oblique photogrammetry technology continues to evolve and improve, its applications in various industries will become increasingly widespread.

The significance of research on large-scale mapping through UAV oblique photogrammetry is primarily reflected in the following aspects: Improving measurement accuracy and efficiency. UAV oblique photogrammetry technology carries multiple lens sensors and collects data vertically with four oblique angles, simulating human visual perception, thereby obtaining richer terrain and landform information (Linder et al 2013). This technology can not only measure basic terrain information but also capture more details such as ground undulations and ground texture, significantly improving measurement accuracy and efficiency. Achieving rapid 3D modeling: Large-scale mapping based on UAV oblique photogrammetry can quickly construct high-precision 3D models. These models not only have a high degree of realism and accuracy but also intuitively display terrain elements such as topography and buildings, providing more intuitive and three-dimensional services for urban planning, land resource survey, geological research, tourism, and other fields.

Promoting the development of related fields: UAV oblique photogrammetry technology can be widely applied in urban planning, land resource surveys, geological research, tourism, and other fields. By obtaining high-precision terrain data and 3D models, it can provide a scientific basis for government decision-making, improving the rationality and scientific nature of urban planning; provide accurate data support for land resource survey, promoting the rational use of land resources; provide rich terrain and landform information for geological research, promoting the progress of geological science; provide realistic scenic models for tourism, enhancing tourists' travel experience. Saving manpower and resources: Traditional large-

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scale mapping requires a significant amount of manpower and material resources, while UAV oblique photogrammetry technology can greatly improve the efficiency and accuracy of data collection, reducing the investment of manpower and resources. At the same time, UAV oblique photogrammetry technology can also achieve rapid data processing and modeling, further shortening the work cycle and reducing costs.

The significance of research on large-scale mapping through drone oblique photogrammetry lies in enhancing measurement accuracy and efficiency, facilitating rapid 3D modeling, promoting the development of related fields, and saving manpower and resources. With the continuous development and popularization of drone technology, this measurement technology will play a more important role in future urban planning, land resource surveys, geological research, tourism, and other fields.

2. Method

2.1 Overall technical process

The overall process is shown in Figure 1. The research content of large-scale mapping through drone oblique photogrammetry mainly includes the following aspects: Drone Oblique Photogrammetry System: Composition and characteristics of the drone oblique photogrammetry system, including hardware equipment such as the drone platform and a 5-lens camera, as well as the acquisition of high-overlap multi-angle surface images from five directions through these devices.

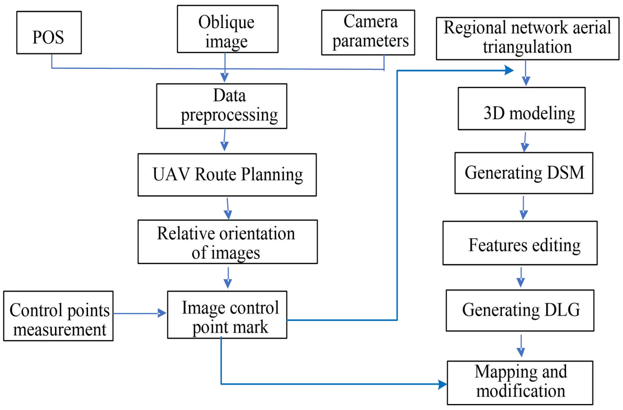

Figure 1. Overall technical flowchart

Image acquisition and processing: The drone oblique photogrammetry system acquires high-quality image data, including flight altitude, aircraft speed, overlap, and POS data of exposure points, and processes and analyzes these data to obtain accurate topographic maps.

Multi-view image joint adjustment: The adjustment methods for images acquired by drone oblique photography, including unconstrained area network adjustment, constrained area network adjustment, and direct orientation of oblique images, to improve the accuracy and precision of topographic maps.

Multi-view image dense matching: Solving the matching problem of oblique images to obtain the same points needed for modeling. Through dense matching of oblique images, high-precision and high-density point cloud data can be obtained, which is the key to achieving fine 3D modeling. Topographic map generation and accuracy evaluation: Generating large-scale topographic maps based on processed image data and evaluating their accuracy and precision. This includes effectively checking the differences between the topographic map surface and the surface level, as well as improving the accuracy of the measured graphics through multiple error measurements and error corrections.

2.2 Photogrammetry Operations

Firstly, it is necessary to clarify the specific requirements and objectives of large-scale mapping, such as the scale, accuracy requirements, and scope of mapping. These requirements and objectives directly affect the subsequent design and data processing flow of unmanned aerial vehicle oblique photogrammetry schemes. Design a drone oblique photogrammetry scheme based on research objectives and requirements. A suitable drone oblique photogrammetry scheme includes selecting a suitable drone platform, camera system, and route planning. At the same time, it is necessary to consider the setting of parameters such as flight altitude, speed, and overlap to ensure that the obtained image data can meet the requirements of large-scale mapping. According to the design plan, implement drone oblique photogrammetry, including the processes of drone takeoff, flight, and photography.

During the measurement process, it is necessary to ensure the stability of the drone and camera in order to obtain high-quality image data. Image data processing and analysis: After obtaining image data, data processing and analysis are required. This includes steps such as image preprocessing (such as distortion correction, and color correction), joint adjustment of oblique images, and dense matching of multi-view images. Through these processes and analyses, three-dimensional information on land features can be extracted from image data, and large-scale topographic maps can be generated.

Generation and optimization of topographic maps: Generate large-scale topographic maps based on the results of processing and analysis. During the generation process, it may be necessary to optimize and adjust the topographic map to meet the requirements of accuracy and aesthetics. At the same time, it is necessary to conduct quality checks on the topographic map to ensure that it meets the research objectives and requirements. Result validation and application: Finally, it is necessary to validate and apply the generated large-scale topographic map. This includes comparing and validating with other data sources such as ground measurement data and other remote sensing data, as well as applying topographic maps to practical projects such as urban planning and environmental monitoring. Through verification and application, the accuracy and practicality of topographic maps can be evaluated, providing support and reference for subsequent research and application.

2.3 Attitude angle measurement

The principle of attitude angle measurement plays an important role in photography processing, especially when it comes to 3D reconstruction and object positioning. This type of measurement typically involves determining the orientation of an object or camera in three-dimensional space. Attitude angles mainly include roll angle, yaw angle, and pitch angle, which describe the rotation of an object or camera relative to a reference coordinate system.

In photogrammetry, the measurement of attitude angle is usually based on specific hardware devices, such as IMU systems, or inertial measurement units, which are devices capable of measuring the attitude angle (such as roll, pitch, and yaw angles) and acceleration of an object in three-dimensional space. IMUs typically include gyroscopes, accelerometers, and some even magnetometers. These sensors work through different principles to provide information about the motion state of objects.

In aerial photogrammetry, IMU systems can be used to assist in obtaining high-precision external orientation elements, including the camera's position (X, Y, Z coordinates) and attitude angles (such as roll, pitch, and yaw angles) at the time of photography. These external orientation elements are crucial for accurately calculating the three-dimensional coordinates of ground points. The measurement principle of the IMU system is as follows:

Gyroscope: Gyroscopes detect angular velocity by measuring Coriolis force. When an object moves at a fixed linear velocity and is also affected by an angular velocity, a Coriolis force is generated in the cross direction. The gyroscope measures the magnitude of this force to obtain the angular velocity of the object. By integrating angular velocity, the attitude angle change of an object can be obtained.

Accelerometer: The principle of an accelerometer is based on Newton's second law, which works by measuring the acceleration of an object in three axes. The mass block in the accelerometer will move under the action of acceleration, and the capacitors on both sides can measure the position of the mass block to calculate the magnitude of acceleration. By integrating acceleration, the velocity and displacement information of an object can be obtained.

Magnetometer: Magnetometers measure the strength of magnetic fields through the Hall effect. The direction of the magnetic field is usually aligned with the geographic North and South poles of the Earth, so magnetometers can be used to determine the orientation of objects.

In aerial photogrammetry, IMU systems are installed on aircraft and work together with aerial cameras. The IMU system provides real-time attitude angle and acceleration information of the aircraft, which is synchronously recorded with the exposure time of the aerial camera. In the subsequent processing, using the data provided by IMU and the internal orientation elements of the aerial camera (such as lens distortion parameters, focal length, etc.), the external orientation elements of the aerial camera can be solved by solving the collinearity condition equation.

Through the real-time data provided by the IMU system, aerial photogrammetry can be conducted without ground control points, thereby improving operational efficiency and reducing costs. At the same time, IMU systems can also provide continuous attitude and position information, which is helpful for high-precision aerial photogrammetry in complex terrain and adverse weather conditions.

3. Experiment and result

3.1 Drone equipment

The DJI Phantom 4RTK UAV is a small multi-rotor high-precision aerial survey drone designed for low-altitude photogrammetry applications, as shown in Figure 2. It is equipped with a centimeter-level navigation and positioning system as well as a high-performance imaging system, making it portable and easy to use. The DJI Phantom 4RTK consists of an aircraft, remote control, gimbal camera, and the accompanying DJIGS RTK App. As a high-precision aerial survey multi-rotor drone, DJI Elf 4 RTK has the following characteristics. Elf 4 RTK is equipped with a high-precision GPS Real-time kinematic (RTK) positioning system that can provide centimeter-level positioning accuracy, making it very suitable for applications in surveying, construction, agriculture, and other fields. The fuselage is made of lightweight materials, which have excellent wind resistance and stability, allowing for efficient flight in complex environments. The Phantom 4 RTK is equipped with a high-definition camera that supports video shooting with up to 4K resolution, allowing for very clear and detailed photos to be taken. The Phantom 4 RTK is equipped with multiple intelligent flight modes such as automatic obstacle avoidance, automatic return, and automatic takeoff and landing, which can greatly improve flight safety and comfort. Long endurance: The Elf 4 RTK is equipped with a high-capacity battery, with a maximum endurance of about 30 minutes, which can support long-term operational tasks.

Figure 2. DJI Phantom 4RTK UAV.

3.2 Overview of the survey area

This survey is conducted in the eastern district of Panzhihua City, Sichuan Province, as illustrated in Figure 3. Panzhihua City is located in the southern part of Sichuan Province, spanning the Hengduan Mountains to the west, the Daliangshan Mountains to the east, the Daxueshan Mountains to the north, and the Jinsha River to the south; The terrain is undulating, with perennial drought and little rainfall, and dense vegetation. The eastern survey area covers 2.298 square kilometers, with a total of 1908 images collected. The survey area has 5 control points and 10 verification points. The heading overlap is 70%, the lateral overlap is 50%, the flight altitude is 100m, and the flight route is set to five directions. Due to the large measurement area and abundant wind resources in the Panzhihua area, using aerial survey cloth to set up image control points will be blown by the wind, and the large measurement area of the unmanned aerial vehicle pool does not support a one-day measurement. The measurement area is shown in Figure 3. The green dot represents the instantaneous position of the sensors.

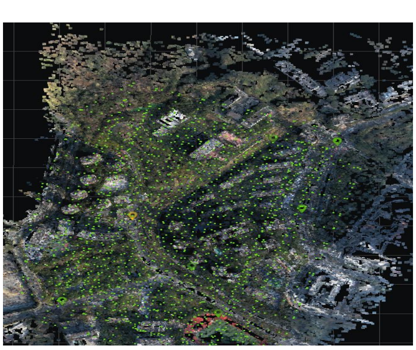

Figure 3. Overview of the survey area.

In this study, handheld RTK was used to collect control points, using the geodetic 2000 coordinate system and the central meridian using 102E, as shown in Figure 4. Then, the Continuous Operational Reference System (CORS) network was used to calculate high-precision differential signals for collecting control points. The basic principles for the layout of image control points: (1) Image control points are generally uniformly arranged according to the measurement area, and should be evenly and stereoscopically arranged within the measurement area. (2) The image control points arranged at the same location should be connected to form a flat high point. (3) The distribution of control points should avoid forming approximate straight lines. (4) Points should be selected as close as possible to the lateral overlapping midline, and when they are more than 3cm away from the azimuth line, they should be arranged separately. Different sizes of image control targets should be set up according to the measurement accuracy to ensure clear and sharp imaging of the targets on aerial photographs and ensure accurate puncture points.

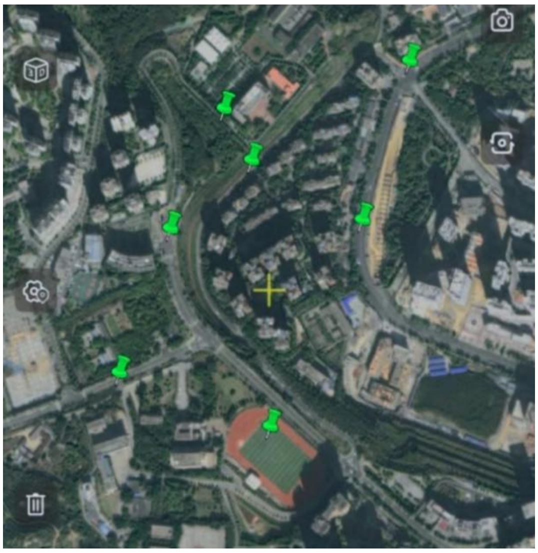

Figure 4. Distribution of control points.

3.3 UAV route planning

The basic requirements for photogrammetric route planning include the following. Route planning should ensure flight safety and avoid collisions with other aircraft and ground obstacles. When planning, it is necessary to fully consider the aircraft's maneuverability, altitude limitations, and the use of navigation equipment such as radar. Route planning requires comprehensive coverage of the target area to ensure that the details of the terrain are captured. According to the characteristics of the terrain and the objectives of the aerial photography task, different flight path forms are adopted, such as strip-shaped flight paths, serpentine flight paths, or grid-shaped flight paths, to achieve the best coverage effect. Route planning requires maintaining a certain degree of overlap between adjacent routes to ensure the continuity of aerial imagery and stereoscopic visual effects. Usually, two methods are used: front overlap and side overlap. Generally, the front overlap is 60% to 80%, and the side overlap is 20% to 30%.

In addition, route planning also needs to consider factors such as route layout, camera scale, and altitude. The camera scale refers to the unit length on the ground corresponding to the unit length on the film, usually in a ratio of 1:10000 or 1:20000. The choice of altitude directly affects the resolution of the image and the coverage range of the aerial survey. Generally speaking, the higher the altitude, the lower the image resolution, but the wider the coverage area.

This photogrammetric survey used a five-directional flight in the eastern area, which has relatively more trees and more complex terrain. Five directional flight is required to better build 3D models. Photogrammetric route planning is the process of determining the aircraft's route and shooting parameters during aerial photogrammetry tasks. The heading overlap used in this study is 70%, and the lateral overlap is 50%. Due to the flight height limit in Panzhihua, the flight altitude is set at an absolute height of 100 meters. The green dots represent the path taken by the drone, while the red dots represent the path from the drone's takeoff point to the start of aerial photography. The aerial photography route is shown in Figure 5. The green and red dot represents the instantaneous position of the sensors in two flights.

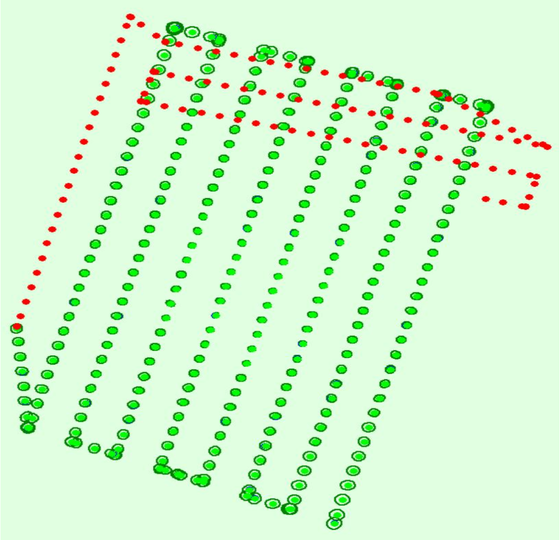

Figure 5. UAV route.

3.4 Digital product generation

The reconstruction of the model requires importing the image information collected by the drone into the Context Capture software, finding the control points on the photographic image, locating all control points on the image, and performing spiking. After completing the puncture point, perform aerial triangulation calculation to obtain an aerial triangulation accuracy report, and ensure that the accuracy report of aerial triangulation calculation is within the allowable error. If the accuracy is not within the allowable error, it is necessary to re-puncture the point and perform aerial triangulation calculation again.

After achieving the desired accuracy in aerial triangulation, set the model parameters and proceed with the reconstruction of the 3D model. This study divided the model into 108 tiles. The Context Capture software is used to reconstruct 3D models by dividing them into tiles, and it took nearly a week to complete the model reconstruction. Figure 6 shows the 3D model reconstructed in this survey area, where the white dots represent the locations captured by the drone camera.

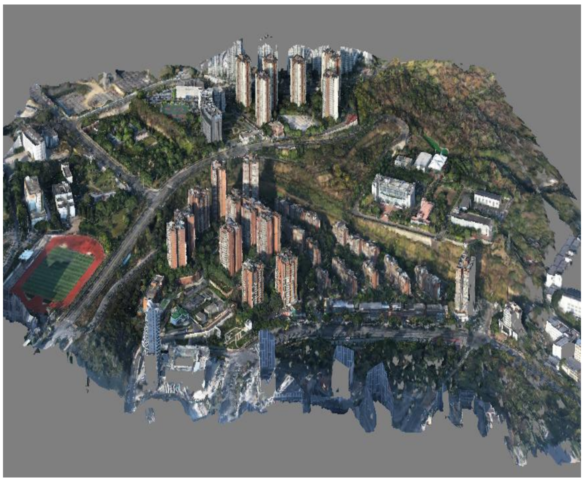

Figure 6. 3D model reconstruction.

3.5 DLG Editing

First, open the reconstructed model in Cass 3D software and edit the topographic map using the corresponding feature symbols for each feature. The collection of feature elements must strictly follow the actual representation and acquisition of the 3D model, and the fuzzy parts of the 3D model should be marked for subsequent on-site surveying and additional research or unmanned aerial modeling to collect data again.

The research field of experiment is mainly focused on houses, with relatively unique characteristic elements. For house collection, regardless of whether the house area is dense or not, it should be collected one by one. Houses of different heights should be collected according to different houses, and during the collection process, the model should be rotated to ensure accurate collection of building edges; In areas with dense buildings, contour lines do not need to be drawn. The water body and road traffic facilities should be expressed correctly, and power lines and communication lines should be fully reflected. During the picking process, collection principles are established based on the different attributes of points, lines, and surfaces. Point attributes should be collected at the center of the point; The position of the centerline of a linear shape set line. The surface attribute must be aggregated strictly according to the outer contour of the feature to form a closed surface and input the attribute. The drawing result is shown in Figure 7.

Figure 7. DLG mapping.

3.6 Accuracy Analysis

7 planar checkpoints are selected within the eastern survey area, and we use GNSS receivers as the data acquisition instrument for the checkpoints. The error was calculated by comparing the measured coordinate values of 7 checkpoints with the corresponding ground point measurement coordinate values on the topographic map, as shown in Table 1. △x, △y and △z denote the residual of the checkpoints in 3D coordinates. △s is the square root error.

Table 1. Checkpoint accuracy assessment.

Checkpoints	△x/cm	△y/cm	△z/cm	△s/cm
JCD1	2.1	1.2	1.3	2.7
JCD2	-1.6	2.3	1.1	3.0
JCD3	-2.3	-2.4	-1.4	3.6
JCD4	2.1	-1.6	1.2	2.9
JCD5	-2.6	2.1	1.3	3.5
JCD6	1.2	-2.6	-1.2	3.1
JCD7	-2.4	-2.3	-1.4	3.6

The mean square error is 3.1cm in the large-scale topographic map points in the survey area. According to the field digital mapping regulations, the mean square error of the 1:500 (nonfield manually adjusted) topographic map points does not exceed 0.3m. It can be concluded that the accuracy of the survey results in this survey area meets the requirements of the 1:500 topographic map specification.

4. Conclusion

The main focus is the application using oblique photogrammetry in large-scale digital mapping. The operational procedures for both office work and filed work are elaborated in detail. In complex areas with mountains and forests, oblique photogrammetry can better collect image data information on ground features. After collecting control point information, we select and edit control points, and perform aerial triangulation analysis. Finally, a complete 1:500 topographic map was generated. The quantitative analysis and visualization results confirmed that the proposed method can meet the requirements of large-scale automated topographic mapping.

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