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Application Research on Close-Range Photogrammetry Acquisition and Processing Technology for Western Campus Library of Panzhihua University

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Abstract

Traditional topographic map surveying typically uses total stations or RTK, which are complex to operate and time-consuming for data collection. Although traditional photogrammetry and spaceborne remote sensing can compensate for the shortcomings of traditional topographic map surveying, they have drawbacks such as untimely information acquisition, insufficient processing accuracy, significant vulnerability to climate, and high implementation costs. UAV oblique photogrammetry can both improve surveying speed and obtain precise 3D information of the survey area. With the gradual maturity of UAV close-range photogrammetry technology, it has been widely applied in 3D modeling of digital cities. Using UAV close-range photogrammetry technology to create real-scene 3D models has become a trend.

Keywords

Close-Range Photography, Refined 3D Modeling, Model Accuracy, UAV Remote Sensing Technology

1. Introduction

At the beginning of the 21st century, satellite communication technology has been continuously advancing, and composite materials have also been innovatively applied. Driven by these two factors, there have been significant breakthroughs in unmanned aerial vehicle (UAV) system technology. This technical equipment has shown a trend of lightweighting and miniaturization, and its key performance indicators, such as flight altitude, endurance, and detection accuracy, have all been systematically improved. With the continuous iteration and upgrading of technology, a variety of types of unmanned aerial vehicles (UAVs) with different functional features have now been formed. They have demonstrated extensive application value in numerous professional fields such as agricultural monitoring, forest resource investigation, meteorological observation, power line inspection, land and resources surveying, project supervision, surveying and mapping, cultural heritage protection, and disaster emergency response [1]. In the field of earthwork measurement, Yang Jingmei's research team innovatively adopted this technology to obtain high-resolution image data, complete the three-dimensional modeling of the target building's real scene, and precisely calculate the earthwork volume with the help of professional software such as EPS. They demonstrated the technical advantages of unmanned aerial vehicle (UAV) proximity photogrammetry technology in earthwork verification work [2].

Photogrammetry, as a new measurement method that integrates unmanned aerial vehicle (UAV) technology with the demands of precise observation, has significantly promoted the development of high-precision 3D modeling and UAV remote sensing technology. It has achieved remarkable application results in early warning of landslide disasters, digital reconstruction of urban space, protection and restoration of historical buildings, and safety monitoring of water conservancy projects. Especially under the facades and eaves blocked by buildings, image information cannot be obtained. Moreover, the photography distance is relatively far, resulting in low resolution of the restored model results and incomplete texture information. This leads to phenomena such as voids and streaks in the final model results, affecting the overall quality and accuracy of the model results.

The innovative idea of this article stems from the actual demands in the fields of geological exploration and disaster monitoring. Considering that traditional manual measurement methods pose safety hazards in dangerous areas such as landslide bodies and steep cliff walls, a new operation mode of using unmanned aerial vehicles (UAVs) equipped with professional measurement equipment to collect data on the target facade at close range is adopted. This mode enhances the security of data acquisition and operational efficiency. It can also achieve sub-centimeter-level precision image acquisition.

2. Technology

Proximity photogrammetry is a precise mapping technology based on optical images. Its core principle is to collect high-resolution digital images of the surface of the target object and reconstruct the spatial information of the measured object by using multi-view geometric relationships. Route planning is a key issue in unmanned aerial vehicle-related research. Route planning refers to designing an optimal flight path that meets the flight performance constraints of unmanned aerial vehicles (UAVs) under the condition of considering the environmental and terrain conditions around the flight area, as shown in **Figure 1**: Three-dimensional Route planning roadmap. When using drones for close-up photography, many issues need to be considered. Firstly, the endurance of the drone should be taken into account. Secondly, under the premise of ensuring quality, the target building and its surrounding environment should also be considered to generate a collision-free close-up route that can meet the modeling requirements.

Unmanned aerial vehicles (UAVs) have the characteristics of flexible takeoff and landing and convenient operation, and are widely used to carry out flight tasks in various industries. The route planning method of UAVs is the prerequisite and key to completing various flight tasks. Under normal circumstances, the route planning method for unmanned aerial vehicles (UAVs) needs to generate a global path that meets the requirements of the flight mission, such as reaching the designated target or completing the coverage of the target scene. At the same time, under the premise of ensuring flight safety and avoiding collisions with obstacles, the optimal route solution under certain conditions must be determined [3].

Proximity photogrammetry and close-range photogrammetry are very similar in principle. Both rely on the fusion of multi-source images to reconstruct the shape and position of objects. But what is different is that close-up photogrammetry is merely a simple superposition of vertical and oblique images captured from a height, while close-range photogrammetry takes close-up shots of every surface of the subject, as if a net completely covers the target, thus ensuring that all images are valid. Close-range photogrammetry has higher requirements for the resolution of images. This requires the drone to take pictures of the target object at an extremely close distance. If the shooting distance of the drone is not close enough, it will not meet the standard of image resolution. This technology can be applied in areas such as smart city construction, landslide detection, industrial inspection, cultural relic protection, and agricultural inspection.

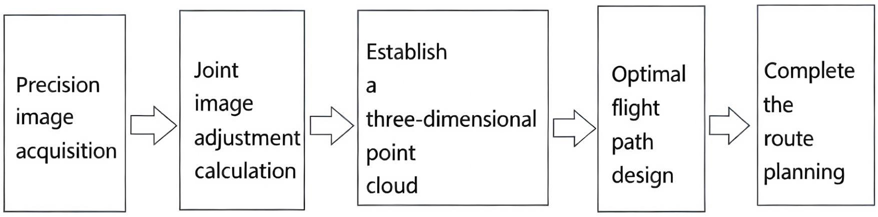

Figure 1. Roadmap of 3D flight path planning.

3. Data Collection Tool

This experiment selects the DJI 3M series quadcopter unmanned aerial vehicle as the close-range photogrammetry data acquisition platform. This model is equipped with a high-precision positioning system, supporting network RTK, custom RTK services, and D-RTK2 mobile stations and other positioning modes. It can achieve centimeter-level precise positioning, providing reliable position and attitude data support for flying around the surface of objects. The device is equipped with a MAV1C3E wide-angle lens, featuring a 4/3-inch CMOS sensor with 20 million effective pixels. The mechanical shutter design eliminates the jelly effect, allowing measurement tasks to be completed without the need to set up ground control points. The 0.7-second rapid continuous shooting interval enhances data collection efficiency, and the 45-minute ultra-long battery life expands the coverage of a single operation and improves fieldwork efficiency. In terms of safety guarantee measures, the use of omnidirectional fisheye lenses can achieve a 360-degree all-round environmental monitoring effect. Users can set the alarm distance, automatic stop threshold, and other parameters according to the actual working scene requirements. It is equipped with a three-axis mechanical pan-tilt system, which has three degrees of freedom of motion: pitch, roll, and yaw. Combined with advanced image stabilization technology, during close-range shooting, high-definition and stable image data can be obtained. For specific technical parameters, please refer to the performance indicators of the DJI 3M drone listed in Table 1.

Table 1. Parameters of the DJI Mavic 3M UAV and camera.

Hardware System	Technical Specification	Specific Type Parameters
Air Vehicle	Overall machine quality (including propeller and power module)	1050 grams
	Battery life performance	The continuous flight time is 45 minutes to significantly enhance operational efficiency and coverage
	Work capacity	A single flight can complete the mapping task of an area of 2 square kilometers
	Rotor wheelbase	380 millimeters
Spatial Orientation	GNSS positioning module	Adopt centimeter-level precision
Camera	Image sensor	4/3 inches
	CMOS sensor	The minimum interval of the mechanical shutter is 0.7 seconds
	Image resolution	640 × 512 pixels
	Optical system	360˚ panoramic fisheye lens A 12-megapixel telephoto camera supporting 56× hybrid zoom
Tripod Head	Stable control system	There are three stable platforms (pitch/roll/yaw)
	Working range	Pitch axis: −90˚ to 35˚
	Dynamic property	The maximum rotational speed is 100 degrees per second
	Angular stability	Error: ±0.007˚

4. Route Planning

4.1. Close to the Principle of Photogrammetry

The principle of image overlap is to obtain object information from different angles and carry out matching and 3D reconstruction of the same named points. It is necessary to ensure that there is a certain degree of overlap between the captured images, close to the requirements of 60% - 80% of the forward overlap and 30% - 60% of the lateral overlap in photogrammetry. Taking the flight shooting of ancient buildings along the long axis as an example, most of the content of adjacent photos needs to overlap. Determine the spatial position and shape of the object by using the information of the overlapping part. The theoretical basis of this measurement method is to construct a stereo vision model by using multi-view images. There should be sufficient overlapping areas between the images. According to the spatial rear intersection algorithm system, the camera parameters can be accurately calculated, and at the same time, the mapping relationship between the image side and the object side coordinate system can be established. In the image side coordinate system, the observed values (u, v) are obtained through direct measurement. The corresponding three-dimensional coordinates of the ground points (X_0, Y_0, Z_0) reflect the actual spatial distribution characteristics of the object being measured. This coordinate transformation process strictly follows the principle equation of colinear 4.1, close to photogrammetry. The specific mathematical Equations (1) and (2) are shown [4]:

$$x - x_0 = -f \frac{a_1(X_A - X_S) + b_1(Y_A - Y_S) - c_1(Z_A - Z_S)}{a_3(X_A - X_S) + b_3(Y_A - Y_S) - c_1(Z_A - Z_S)} \tag{1}$$

$$y - y_0 = -f \frac{a_2(X_A - X_S) + b_2(Y_A - Y_S) - c_2(Z_A - Z_S)}{a_3(X_A - X_S) + b_3(Y_A - Y_S) - c_3(Z_A - Z_S)} \tag{2}$$

Identify defect areas through model quality assessment; Based on the defect features, formulate differentiated supplementary shooting strategies. Use handheld devices to supplement the collection of accessible but occluded areas. Conduct multi-angle surround shooting in high-altitude areas to supplement data. All supplementary images must cover multiple perspectives and contain sufficient detailed information. The supplementary images were integrated into the original dataset for secondary processing. Through multiple iterations and optimizations, the model quality met the expected standards, and geometric defects were eliminated.

Select the imported route in the flight path planning (as shown in **Figure 2**), and conduct operations on the planning target after confirming the altitude. For areas with voids, missing parts, or those that cannot be photographed, manual supplementary shooting should be used.

Figure 2. Schematic diagram of the route planning for the drone close-up photography.

4.2. Precautions for Proximity Photogrammetry Operations

In terms of the technical implementation of the operation, the following key links should be strictly controlled. Firstly, terminal equipment for route planning should be equipped. When the safety distance between the preset flight trajectory and ground obstacles does not meet the specified requirements, the route parameters can be adjusted in a timely manner. For the situation where data collection is interrupted due to narrow flight channels, the efficiency of field work can be improved by dynamically optimizing the aerial survey distance parameters. For building facades with high reflective characteristics, operations should be carried out during periods with smaller solar altitude angles to prevent the mirror reflection phenomenon caused by intense sunlight from interfering with image quality and ensure the geometric accuracy of the 3D reconstruction model. Before the operation, a special meteorological assessment should be conducted to rule out strong winds with wind speeds exceeding 5m/s to avoid affecting the stability of the aircraft. A clear day should be selected to prevent overcast clouds from causing RTK positioning to lose lock and affecting the accuracy of the aerial triangle calculation. Based on the battery life of the aircraft, the aerial survey area is dynamically adjusted according to the remaining power, and each aerial survey task is controlled within the range that can be completed in a single flight to prevent the mission from being interrupted due to insufficient power.

5. Data Processing and Analysis

5.1. Data Processing

After completing each mission, DJI drones store relevant data in the built-in SD card of the camera and generate independent mission folders containing data files such as image photos, RTK positioning information, and POS attitude information. Due to factors such as drone shooting angles, building occlusion, and missed shots, data loss may occur. After data collection, the first step is to check the quality of the acquired photos. Then, import the field-collected photos into modeling software and check the POS information to see if there are any missed shots. If such situations occur, timely re-flight and re-shooting should be conducted for non-compliant areas. Additionally, aerial photography involves multiple flights over extended periods, resulting in temporal and spatial differences during actual flights. Color differences between collected images are inevitable. Therefore, it is necessary to check for color bias in images and use correction techniques (such as histogram equalization and color balance) to repair abnormally exposed photos [5]. Finally, import images captured from multiple angles into the software. First, use spatial triangulation to calculate the position and attitude of images in three-dimensional space. In the next step, perform feature extraction, feature matching, and geometric correction to achieve three-dimensional reconstruction.

5.2. Image Reconstruction

Import the qualified images into the modeling software (ContextCapture) for 3D reconstruction. Verify at the photo location information whether there are any omissions or unqualified situations. If there is any, immediately conduct local supplementary shooting of the areas where the missed fit is not qualified. Then, proceed in sequence: For 3D reconstruction, start the "New Reconstruction Project" and select the "3D Reconstruction" mode. After delineating the processing range, perform block processing to reduce the data volume. At the same time, set the spatial reference coordinate system, such as CGCS2000, and the central meridian 102˚E to generate a triangular mesh model. For the missing areas of the model (including occluded parts and areas with blurred textures), manual supplementary shooting is required to supplement multi-angle image data, and software tools should be used to repair holes and distortions, thereby enhancing the integrity and geometric accuracy of the model. In the texture mapping and output stage, based on the camera parameters and the original image, the texture information is mapped onto the three-dimensional mesh surface to eliminate stitching seams and exposure differences to enhance the sense of reality. Finally, the final model is exported in standard formats such as OBJ, LAS, and DSM for use on platforms like GIS and CAD.

5.3. Interpretation of Result

This 3D reconstruction went through three construction iterations. The time for aerial triangulation was 120 minutes, and the actual time for 3D modeling was 15 hours. A total of 2568 images were involved in the final reconstruction. The model is almost the same as the actual building, with no problems such as cavities or flying spots. The exposure is accurate, and the brightness is moderate. The window sills, tiles, pipes, fonts, and other elements of the building are clearly visible. The accuracy verification method involves selecting five known coordinate points as verification benchmarks. These inspection points are introduced during the aerial triangulation calculation process, and the accuracy performance of different control point layout schemes is evaluated through comparative analysis. It should be particularly noted that the calculation accuracy of aerial triangulation directly affects the quality of all subsequent processing links.

In the field of aerial photogrammetry, the accuracy of all trigonometric solutions will directly have a decisive impact on the overall accuracy of the subsequent data processing procedures. The calculation formulas for the errors of control points and inspection points are shown in Equation (3). The accuracy grades close to photogrammetry are shown in **Figure 2** [6]. This measurement is a three-dimensional modeling, as shown in **Table 2** and **Table 3**.

$$m = \sqrt{\frac{\sum_{i=1}^{n}\left(\Delta_i \Delta_i\right)}{n}} \tag{3}$$

Accuracy analysis shows that this method performs well in both planar position control point measurement and elevation control point measurement. Whether it is the positioning error of individual control points or the overall mean error index, it fully meets the technical requirements of large-scale mapping standards. In the 1:500 scale topographic mapping work, both the planar mean error and the elevation mean error have reached the accuracy stipulated by the relevant national surveying and mapping standards.

Table 2. Accuracy levels of close-range photogrammetry.

Application Area	Typical Accuracy Requirements	Remark
Industrial inspection (parts)	0.01 - 0.1 mm	The target needs to be calibrated and the light source fixed
Digitalization of cultural heritage	0.1 - 1 mm	High-resolution camera captures from multiple angles
Building deformation monitoring	1 - 3 mm	Regular retests and comparisons are required
Analysis of geological structure	5 - 10 mm	For large-scale scenes, low overlap is also acceptable
3D modeling	1 - 5 cm	Emphasize visual effects rather than geometric accuracy

Table 3. Accuracy of four-point checkpoints.

Parameter	*dx* (m)	*dy* (m)	*dz* (m)	3D Error (m)	Vertical Error (m)	Horizontal Error (m)
RMS	0.033	0.034	0.074	0.087	0.074	0.047
Median	0.003	0.006	−0.025	0.061	0.025	0.044

Error details: Control point error

ID	The Number of Photos with Dots; Number of Visible Photos	RMS (PX)	Forward Intersection Residuals (m)	Horizontal Error (m)	Vertical Error (m)	3D Error (m)	*dx* (m)	*dy* (m)	*dz* (m)
z1	8392	0.75	0.015	0.015	0.013	0.02	−0.012	0.009	-0.013
z2	10,482	1.623	0.034	0.033	0.037	0.05	−0.033	0.003	-0.037
z3	9422	2.219	0.047	0.048	0.054	0.073	0.028	0.038	-0.054
z4	11,475	3.349	0.073	0.075	0.008	0.075	0.055	−0.051	0.008
z5	9234	1.602	0.037	0.041	0.006	0.041	−0.033	0.025	0.006
z6	6241	1.628	0.035	0.048	0.167	0.174	0.018	−0.212	

This paper constructs an accuracy evaluation system by using the deviation values between the measured coordinates of the control points and the measured coordinates on the drawing. The experimental results show that the maximum deviation of the planar coordinates is 0.009 meters in the X direction and -0.009 meters in the Z direction. The specific distribution of error values can be referred to Table 4. After system verification, all the error parameters of the data obtained from this measurement comply with the industry norms and meet the technical requirements close to the photogrammetry accuracy standards (The final result is shown in **Figure 3**).

Table 4. Coordinate errors.

Location Name	RTK Measured Coordinates			Graphical Coordinate Measurement			Coordinate Difference		
	X	*Y*	*Z*	*X*	*Y*	*Z*	*dX*	*dY*	*dZ*
1	*310.662	*677.764	1296.43	*310.660	*677.760	1296.56	−0.002	0.003	−0.007
2	*310.46	*620.969	1296.839	*310.46	*620.969	1296.843	0	0	−0.004
3	*280.204	*624.997	1296.778	*280.199	*624.986	1296.786	0.005	0.009	−0.009
4	*279.562	*655.83	1296.352	*279.559	*655.826	1296.366	0.009	0.004	−0.006
5	*279.22	*691.867	1294.007	*279.23	*691.872	1294.011	−0.001	−0.005	−0.004
6	*305.9	*691.816	1295.837	*305.16	*691.810	1295.839	−0.007	0.006	−0.002

Figure 3. 3D reality model.

6. Epilogue

This paper is based on the fact that the unmanned aerial vehicle (UAV) close-range photogrammetry technology can collect highly accurate, real-time image data of buildings and structures. It has completed the highly automated processing of multi-view images and automatically identified and matched the feature points of ground objects by using image processing and dense matching technology, generating a huge amount of three-dimensional point cloud data. Texture mapping is carried out with real images. A high-precision and texture-rich real-scene 3D model of the building was constructed, reproducing the spatial position, structural features, and texture information inside and outside the house. This method makes the mapping work of building facades more efficient and accurate, effectively reducing human and time costs. It can provide important data support for decision-making and design in fields such as architectural design, engineering construction, and urban planning.

Compared with traditional measurement methods, the performance advantages presented by unmanned aerial vehicle (UAV) close-up photography technology are more prominent. It has high data collection efficiency and strong environmental adaptability. The operation threshold is low, and non-professionals can master it after training. It can solve the problems of collecting near-ground texture loss and occluded areas. The generative model has high resolution and realistic textures. It can also avoid surface distortion, voids, and other defects. Experiments show that the geometric accuracy and visual effect of the three-dimensional model constructed by this method are close to those of real buildings. Integrating multiple photography techniques can achieve multi-level three-dimensional reconstruction to meet the accuracy requirements of different scenes.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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