Influence of Image Overlap on Quality of 3D Reconstruction Based on Aerial Images

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***Abstract*—3D reconstruction technology based on aerial images of drone has been widely used in many fields. In order to obtain high-quality 3D reconstruction results, when planning the aerial route of the drone, it is necessary to determine the image overlap, shooting distance, shooting angle, altitude, etc.. This paper main analyzes the effects of different image overlaps on reconstruction results by using the relevant parameters of three aerial routes in a practical case.**

I. Introduction

3D reconstruction technology based on aerial image of drone has been widely used in geodetic surveying, disaster monitoring, meteorological monitoring, military applications, resource surveys and many other fields.This approach saves a lot of cost and time compared to active interference to detect targets and laser scans[1] that collect depth information. UAV (Unmanned Aerial Vehicles) technology has many advantages such as high time efficiency, high resolution, low cost, low risk, etc.. Using the advantages of UAV and adding remote sensing equipment, high-resolution cameras, other equipment, the final acquisition of large-scale scene images. It has become one of the important technical means for obtaining data in geospatial information. The quality of the 3D model is closely related to the image acquisition process, such as camera shooting distance, image overlap, shooting angle, altitude and so on. According to the theory and experience of aerial surveys, as well as the relevant standards, the greatest possible overlap rate is required to achieve the desired reconstruction results. But this will greatly increase the workload of aerial photography and reconstruction, and limit efficiency. Therefore, research the quantitative relationship to provide a basis and reference for seeking a balance between accuracy and efficiency.

II. Related Work

Reference [2] discusses the selection of images and e-valuates the impact of different acquisition methods on the dataset. One of the reference objects is the object named Testy developed by Prof. Dr. Ralf Reulke and Martin Misgaiski from the Humbold University Berlin for the evaluation of 3D measurements methods, It is about 35cm high and contains different geometric structures, 46 images were acquired in a circular shape around the object. The results show that the accuracy is improved as the mean intersection angle of increases, and the 3D model is also improved due to high redundancy. Each pixel is observed in many images, which causes the outliers to be suppressed and the noise to be reduced. When the overlap of the two images becomes lower, the 3D model is made to have lower integrity. The image overlap is large, resulting in higher redundancy and increased processing time.

Reference [3] introduced a three-dimensional reconstruction experiment based on a brick wall. SfM (Structure from Motion) reconstruction using non-commercial platform VisualSfM, capturing and processing different image sets, and implementing multi-view based 3D reconstruction. The geometrical accuracy and point cloud distribution of the 3D model are analyzed separately from the laser point cloud data obtained by the laser scanner. The results show that larger shooting angles (relative to the camera position and the normal direction of the wall) can significantly reduce data integrity, geometric accuracy and point uniformity. In general, it is recommended that the drone check a relatively large distance and a small shooting angle. In addition, by adding a set of compensation images, the reliability of the data can be significantly improved.

Three different shapes, volumes and areas of buildings were reconstructed in three dimensions. Due to the complexity and size of the reconstructed surfaces, the distance and overlap of the targets are different. Agisoft photocan software is used for modeling and processing from 3D, extract reference point coordinates from 3D model. According to the relative distance, the volume and area are quantified, and the quality of the model reconstruction result is evaluated by comparing with the actual value, as in [4].

As mentioned in reference [5], photogrammetry requires that the shooting overlap be at least 60% to ensure the quality of the model. Since both resolution and overlap have an impact on measurement accuracy, researchers have proposed formulas to quantify the relationship between quantities. Through experiments, the researchers gave the relationship between measurement accuracy and processing time. Although the shooting schemes for such problems are often shots perpendicular to the ground, and the application of the text is in the field of vegetation monitoring, the principle formula and experimental design still have research and reference value.

III. Aerial Photography and Reconstruction Experiment

The experimental aerial photography equipment adopts the DJI UAV Mavic Pro[1] with its own pan/tilt and camera, which is lightweight and easy to operate. The three-axis gimbal

[1] https://www.dji.com/uk/mavic.

TABLE I
AERIAL PHOTOGRAPHY PLAN

Dataset ID	Flight Time	Num.of Images	Num.of Routes	Frontal Overlap(%)	Side Overlap(%)
A	26m35s	82	3	80	60
B	17m14s	55	2	80	40
C	16m56s	27	2	60	40

controller camera can capture 12 Megapixel super resolution (4000x3000) photos, image sensor 1/2.3 inch CMOS, focal length 26mm (35mm format equivalent), the drone has the longest flight time of 27 minutes.

The object of this reconstruction experiment is the landmark building named "Dianlidalou" (means "The Power Building" in Chinese) in our compus. The building has 32 floors, is about 170m long, 60m wide and 150m high.

The aerial ground station selects DJI GS PRO [2](iOS V1.8.0) to realize different route planning and parameter setting. DJI GS Pro ground station can easily plan complex route missions and realize automatic flight point flight operations.

A. Aerial Image Dataset

Due to the high height of the building, if the traditional orthomorphism from the sky is used, the resolution of the building will be quite different. Therefore, the building was subjected to a circular orthophoto (rounded by a roof with a radius of 180m) and three flight routes were obtained, as shown in Fig.1. Three plans with different overlap are planned using DJI GS Pro, three Plan aerial photography flights were performed using Mavic Pro and three aerial image sets were obtained. See Table I for relevant parameter.

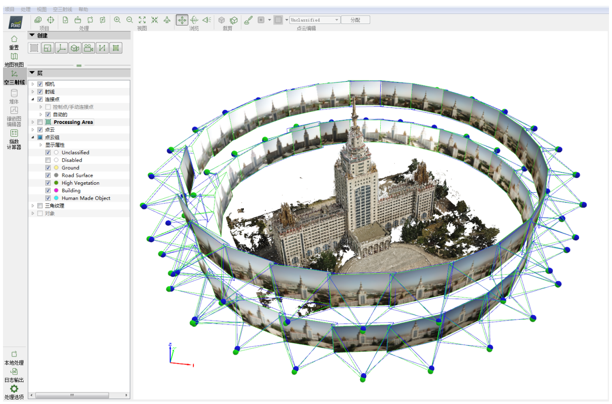

Fig. 1. Circular flight

B. Image Control Point Dataset

The reconstruction object is a relatively large-scale building, and it is necessary to collect more image control points as GCPs (Ground Control Points) and CPs (Check Points) of the reconstruction process.

[2]https://www.dji.com/uk/ground-station-pro/info.

TABLE II
DATUM POINT COORDINATE DATA STANDARD DEVIATION

Number	Mark	Sigma X(m)	Sigma Y(m)	Sigma Z(m)
1	North A	0.022	0.025	0.043
2	North B	0.019	0.019	0.035
3	North C	0.026	0.022	0.054
4	West A	0.013	0.013	0.025
5	West C	0.015	0.014	0.028
6	West B	0.015	0.015	0.025
7	South A	0.012	0.013	0.026
8	South B	0.016	0.014	0.027
9	East A	0.018	0.014	0.035
10	East B	0.017	0.013	0.037

It is difficult to collect image control points directly on the surface of the building such as Danlidalou. With the datum points and the total station(PANTX R-202), we observed the image control points marked on the surface of the building and obtained the points' WGS-84 geodetic coordinate.

In recent years, there is the FindMC, a high-precision centimeter-level positioning service based on RTK (carrier phase difference) technology, suppoted by Qianxun Spatial Intelligence Inc.[3], provides service via cellular network in most regions in China. Dependent on the FindMC, the enough datum points we need have been successfully obtained by a RTK terminal. The standard deviation of the datum points are shown in Table II, and the points' distribution diagram is shown in Fig.2.

Consider that the image control points should be evenly distributed, so that the image control points are distributed around the building(including the building body and the ground). Some image control points are selected as GCPs during reconstruction, and the rest are used as CPs (see Table III). The geometric accuracy of each model reconstruction result is objectively and quantitatively evaluated based on the reconstruction error.

Fig. 2. Datum point distribution

C. 3D Reconstruction Processing

The experiment uses Pix4Dmapper software for 3D reconstruction, used the optimal processing, the processing workstation used CPU: Intel(R) Xeon(R) CPU E5-1620 0 @ 3.60GHz,

[3]https://www.qxwz.com/en/aboutus.

GPU: NVIDIA GeForce GTX 1070 Ti, RAM: 32GB, the operating system is Windows 7 Ultimate, 64-bit, shows the results of reconstructing the model through three different datasets A, B, and C, as shown in Fig.3.

IV. Data Analysis

A. Geometric Accuracy

Evaluate the geometric accuracy of important indicators of 3D models. In order to analyze the geometric accuracy, first, the image control point will be obtained by the total station converting the feature points in the 3D model to the same representation in the same coordinate system, Then compare the feature points in the reconstructed model with the corresponding checkpoints, calculate the displacement error of each checkpoint, each corresponding feature is a set of points. Mean, Sigma, and RMSE respectively represent the average errors, standard deviation, and root mean square error of check point errors in different datasets.

Table III shows the displacement errors of the X, Y, and Z axes in the 3D model generated by the datasets A, B, and C. The ”-” indicates that the model reconstruction is incomplete and no correspondence is found feature point. The results show that the geometric accuracy error of the 3D model generated based on the A and B datasets can be kept at the centimeter level. The geometric accuracy error of the 3D model generated based on the dataset C has reached the decimeter level, and the reconstructed 3D model features are obvious lack.

RMSE is the most representative error in the project. It considers the average error and standard deviation, and the CPs RMSE of three different datasets, as shown in Fig.4.

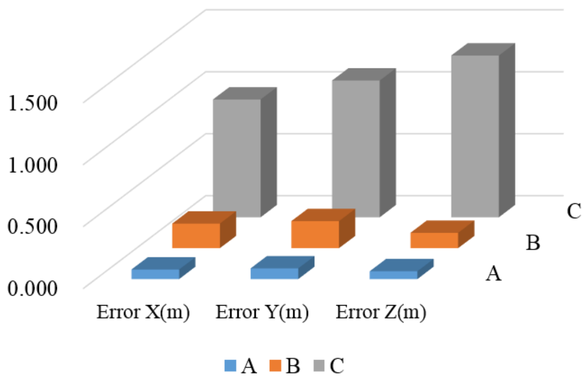

Fig. 4. Check points RMSE

According to the relevant references and the official Pix4D manual, the recommended frontal overlap is at least 75% and side overlap is at least 60% in most cases. Through experiments, it is found that the complete 3D model can also be obtained through the dataset B. It is found in Fig.4 that generating a 3D model based on the dataset A has less error, the dataset B is second, the dataset C has a large error, and the 3D model generated based on the dataset C is not complete. So it is recommended the overlap of the target image of the drone must be maintained at more than 60% of the frontal overlap and 40% of the side overlap.

TABLE IV
Some of Density Parameters in the Reconstructed Models

Parameters	Dataset A	Dataset B	Dataset C
Median of Matches Per Calibrated Image	6305.22	3972.21	3662.77
Number of 2D Key point Observations for Bundle Block Adjustment	512984	278040	99117
Number of 3D Points for Bundle Block Adjustment	203568	118333	46276
Number of 3D Densified Points	49920893	45375879	18978787
Average Density(per m^3)	11.9	20.16	38.8
Time for Point Cloud Densification	04h:16m:57s	02h:08m:49s	22m:11s
Time for 3D Textured Mesh Generation	35m:26s	34m:15s	16m:59s

B. Other Parameters

Table IV shows the relevant parameters obtained based on different datasets of A, B and C, including median of matches per calibrated image, number of 2D key point observations,number of 3D points for bundle block adjustment, number of 3D densified points, average density (per m^3), time for point cloud densification and time for 3D textured mesh generation.From Table IV, it can be found that the high-overlap generation model has the largest number of dense point clouds, but the lowest average density, which is different from the expected result, because the high-overlap image will cover a broader area.

V. Conclusion

Experiments and analysis show that the 3D model generated based on higher image overlap degree has higher geometric precision, and the more the dense point cloud, the more uniform the point cloud distribution and the smaller the number of holes. The geometric accuracy error average of the 3D model generated based on the A and B datasets can be kept at the centimeter level. If no special high geometric accuracy is required, the overlap of the dataset B can be considered, which will save a lot of cost and time. In this paper, through the experimental test of the building, the influence of different image overlap degree on the quality of 3D reconstruction model is considered. The lower image overlap degree can significantly reduce the geometric accuracy, integrity and point uniformity of the 3D model. In general, for the 3D reconstruction of building objects, it is recommended that the UAVs use aerial image orientation with more than 60% of the frontal overlap and more than 40% of the side

(a) Dataset A (b) Dataset B (c) Dataset C

Fig. 3. 3D models based on different datasets

overlap. The research results provide reference value for the actual aerial photography application of the drone.

VI. Future Work

This experiment uses the DJI Mavic Pro drone for aerial photography tasks. the captured image reaches the GPS position accuracy. With the development of RTK-GPS technology, the application of more lightweight and smaller devices in commercial products in the future can greatly improve the accuracy of position information of aerial images in the world coordinate system. The process of 3D reconstruction of aerial image directly using high-precision GPS information will become simpler and the reconstructed model will be more accurate. In the future research, the 3D reconstruction method with high-precision GPS images can be further studied.

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TABLE III
Check Point Error

Check Points	Error X(m)			Error Y(m)			Error Z(m)		
	A	B	C	A	B	C	A	B	C
N7	-0.098	-0.306	1.402	0.101	0.461	-0.932	0.088	0.179	2.364
N8	-0.221	-0.441	0.133	-0.112	0.526	-0.422	0.007	-0.051	1.026
S1	-0.069	0.048	-1.305	-0.080	0.002	2.052	-0.045	0.003	-1.502
S4	0.006	0.180	-0.430	-0.014	-0.155	1.190	-0.084	-0.147	-0.968
S6	0.010	-0.151	-0.575	-0.045	0.093	0.588	0.048	-0.047	-0.322
E2	0.001	-0.056	-	0.060	0.037	-	0.057	-0.049	-
E3	-0.019	-0.059	-	0.037	-0.018	-	-0.009	-0.158	-
W1	-0.018	-0.023	-	-0.032	0.099	-	0.015	-0.059	-
W2	-0.025	-0.075	-	-0.017	0.065	-	0.004	-0.015	-
W3	0.028	-0.078	-	-0.001	0.075	-	0.009	-0.007	-
G8	-0.078	-0.015	-1.106	0.065	-0.148	0.542	-0.113	0.232	-0.538
G5	0.001	0.330	-	0.217	0.084	-	0.112	-0.204	-
Mean	-0.040	-0.054	-0.313	0.015	0.094	0.503	0.007	-0.027	0.010
Sigma	0.066	0.191	0.898	0.085	0.197	0.983	0.063	0.121	1.305
RMSE	0.077	0.199	0.951	0.086	0.218	1.104	0.063	0.124	1.305