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1:500 Scale Aerial Triangulation Test with Unmanned Airship in Hubei Province

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Abstract. A new UAVS (Unmanned Aerial Vehicle System) for low altitude aerial photogrammetry is introduced for fine surveying and mapping, including the platform airship, sensor system four-combined wide-angle camera and photogrammetry software MAP-AT. It is demonstrated that this low-altitude aerial photogrammetric system meets the precision requirements of 1:500 scale aerial triangulation based on the test of this system in Hubei province, including the working condition of the airship, the quality of image data and the data processing report. This work provides a possibility for fine surveying and mapping.

1. Introduction

Timely and fine surveying and mapping is necessary in modern society, which ask for application of UAVS for low altitude aerial photogrammetry[1]. The low altitude aerial photogrammetry has an optic advantage[2], but it is difficult to apply this low altitude advantage. The load of the sensor should be small and lightweight since the UAV platform is flying with low speed while working. Weight miniaturization of the sensor using special technology is required with the challenge of high resolution and high precision mapping. Meanwhile, the UAV platform is lightweight with low wind resistance and unstable flight attitude, which lead to the acquired images having high tilt angle and different scales. Thus, the photogrammetry software to deal with these images is essential.

UAV is related to unmanned aircrafts, including fixed wing unmanned aircraft, unmanned helicopter and unmanned airship, etc[3]. Different unmanned aircraft have respective advantages and are applied to different ranges. Fixed wing unmanned aircraft is mostly upgraded from model airplane, and load of model airplane for low altitude aerial photogrammetry is less than 10kg. Therefore most of the sensors are with single camera and applied to emergency surveying and mapping. Double-combined camera loaded in fixed wing unmanned aircraft is designed for large-scale (1:1000~1:5000) mapping. Unmanned helicopter for low altitude aerial photogrammetry flies in very low height and it is very flexible. Effective load of unmanned helicopter ranges from 3 to 30kg but the substantial vibration of the rotor engine can easily cause the image blur and it is very dangerous to operate in mountain areas[4]. Unmanned airship is filled with helium, with flying height between 50~2000m and flying speed between 30~70km/h, and it is safe to fly over the city. Effective load of unmanned airship

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is higher than 15kg[5][6]. Consequently, unmanned airship can obtain more clear images and is more applicable to large-scale mapping.

A developed unmanned airship photogrammetry system is introduced in this paper. The unmanned airship platform CK-FT120 including structure, performance and flight control system is described in Section 2; A four-combined wide-angle camera is described in Section 3 based on the load requirement of unmanned airship and the need of fine mapping; A new software MAP-AT for aerial triangulation is designed and the LSM image matching method based on SIFT is described in Section 4. The test data of this system in Hubei province in China is analyzed to verify the feasibility of 1:500 scale aerial triangulation in Section 5.

2. The Unmanned Airship CK-FT120

The unmanned airship CK-FT120 mainly consist of bag body, head and tail, etc [7]. The parameters are shown in Table 1.

Table 1. The parameters of CK-FT120.

Total dimensions		Main airbag		Weight(W)		Performance	
Total length	15.3m	**Volume**	117m^3	**Taking off W**	145kg	**Max wind resistance ability**	10.8~13.8m/s
Total height	4.9m	**Max diameter**	3.8m	**Max fuel W**	15kg	**Max flying speed**	70km/h
		Side airbag volume	20m^3	**Task load W**	15kg	**Max altitude**	2000m
						Residence time in the air	2h

The flight control system plays as the pilot role in UAV, and may be referred to as the autopilot[8]. The minimum requirement of the flight control system is that airframe keeps flying smoothly along a given route under normal wind condition. Quality of the images are controlled by the accuracy of positioning and altitude determination of the flight control system. Images will overlap when flight control system positioned in improper position or altitude.

The limiting value of Δ is shown in Table 2[1], when the offset (Δ) of the longitudinal and lateral overlap degree is lower than 10% of the image width.

Table 2. The limiting value of Δ of the longitudinal and lateral overlap degree

Mapping scale	Flight altitude(m)	Single camera		Single camera	
		Frame width(m)	Δ(m)	Frame width(m)	Δ(m)
1:500	150	150	15	300	30
1:1000	300	300	30	600	60
1:2000	600	600	60	1200	120
1:500	1500	1500	150	3000	300

CK-FT120 adopts a new and soft stable control system for requirements of load weight. This soft stable platform comprise damping type stabilization platform, MTI posture measuring instrument, data recorder and data processing software. The designed damping type stabilization platform is shown in Fig.1, and vertical downward movement of the camera is mainly supported by gravity of the sensor system[9]. MTI is a miniature of measuring attitude and heading system, as shown in Fig.2. Data recorder is developed by MCU, and it records the position once the camera exposed for subsequent data processing. Data processing software is a self-calibration function for the camera, introduced in Section 3.

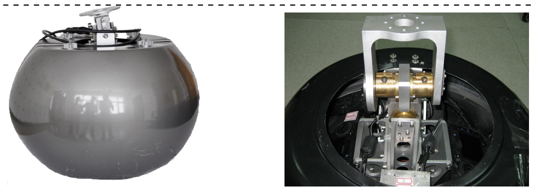

Figure 1. The damping type stabilization platform.

Figure 2. MTI posture measuring instrument.

3. The Design of Four-combined Wide-angle Camera

There are a number of developed products of four-combined wide-angle camera, i.e., and mechanical structures of the advanced product DMC and UCD are shown in Fig.3a and Fig.3b[10][11]. The narrow field angle result in low elevation precision of aerial photography measurement, and its accuracy only meet the requirements of 1:2000 scale mapping according to present report. The Chinese product SWDC has a wide view angle and its mechanical structure is shown in Fig.3c[12]. To get strong stability of the mechanical structure and high accuracy of the exposure control circuit, to avoid and eliminate the errors caused by mechanical deformation and synchronization exposure time difference [7], it is necessary to design the camera system with large volume and higher than 100kg weight, which is not applicable to small UAV.

The structure of the new four-combined wide-angle camera is shown in Fig.4 and the performance is shown in Table 3.

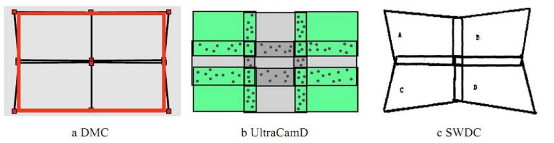

Figure 3. Mechanical structures of DMC, UCD, SWDC camera.

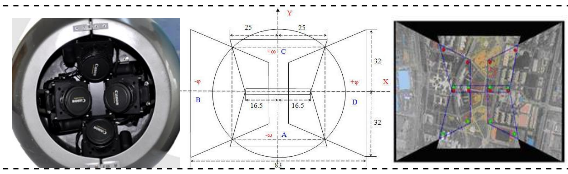

Figure 4. The structure of four-combined wide-angle camera.

Table 3. The performance of the four-combined wide angle camera.

Flight height(m)	Frame(m^2)	Image resolution(cm)	The parameters	
150	200×200	5	**The field angles**	124° ×90°
300	400×400	10	**The focal length**	4mm
450	600×600	15	**Max resolution**	8000p×8000p
600	800×800	20	**Pixel size**	8μm
900	1200×1200	30	**Total weight with stabilization platform**	15kg

The four-combined camera applied the special light and small mechanical structure to meet the UAV load requirements, result in relatively large image displacement caused by mechanical deformation and affect on the image splicing quality. Self-calibration of the four-combined camera correct the minor changes automatically, obtain accurate orientation relationship between cameras, and reduce image splicing error[13]. Self-calibration of four-combined camera is shown in Fig.5. Each camera is calibrated to obtain its precise inner orientation elements by outdoor calibration field before the self-calibration. Relative exterior orientation elements of the images are calibrated by the accordant points from feature matching in overlap areas and the accordant points could eliminate the independent error from each camera and ensure the spliced images be accurate. The system error is eliminated and the mean error of the image splicing is limited to 0.2 pixels after self-calibration, and the relative relationship between cameras is established precisely.

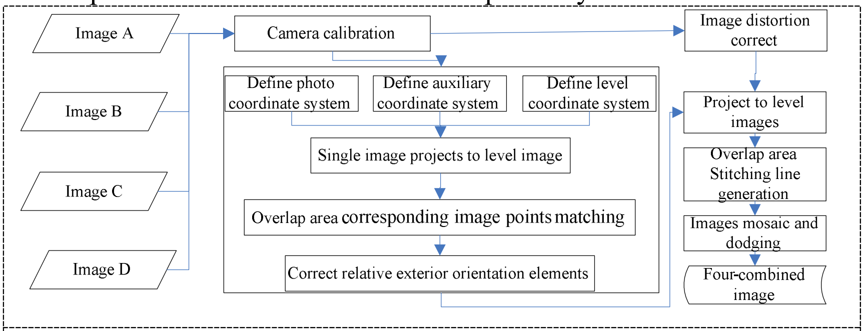

Figure 5. Self-calibration process of four-combined camera.

4. The Aerotriangulation Software MAP-AT

Aerotriangulation software MAP-AT processes four-combined images to obtain attitude parameter with high precision and orientation elements, including relative and absolute orientation extraction of image feature points and block adjustment, and it is possible to calculate the exterior orientation elements of images from each camera based on the result of self-calibration.

The images might pitch, roll or yaw (Pitch and roll are over than 5°, Yaw is over than 15°) even though the UAV platform is lightweight, small-sized and low-height flying. Heavy geometric deformation and noticeable gray values differences would occur in different images that pitched and rolled significantly, and lead to increasing of matching difficulty. Matching mostly fails when image yaws greater than 15°. Multi-scale LSM algorithm based on SIFT feature with epipolar and homography constraints is proposed in view of the above problems. The originals are sharpened using Wallis filtering algorithm before SIFT matching. Fundamental matrix and homography matrix are estimated, and the false matching points are eliminated using RANSAC algorithm on the basis of the matching result. The feature points are extracted by Harris operator and matched with epipolar and homography constraints. Meantime, bidirectional and concordance matching of correlation coefficient further improves the matching reliability. LSM is completed ultimately at the bottom of the pyramid, and obtain the sub-pixel accuracy.

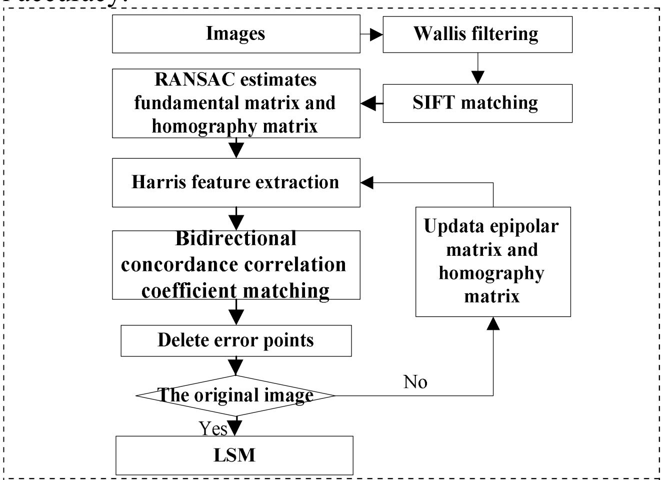

Figure 6. The Image Matching Flow Chart.

5. Test in Hubei Province

The test carries out in Hongtu Airport in Hubei Province in China. The terrain height ranges from 60 meters to 40 meters, and is a flat terrain. Flight environment is mist and the visibility is 5km. The airship obtained 110 pictures from 4 lines in 30km^2 region, with a flight height of 300m. Flight path is shown in Fig.7, and control points of images are shown in Fig.8.

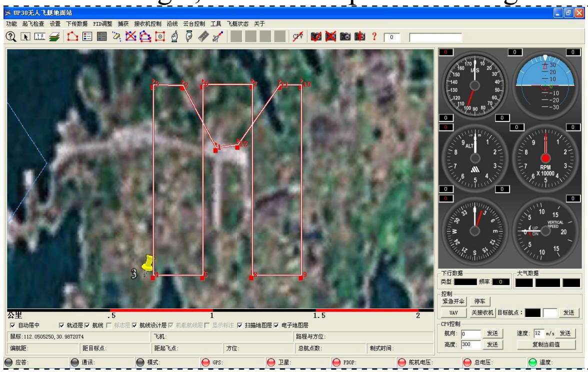

Figure 7. The flight line.

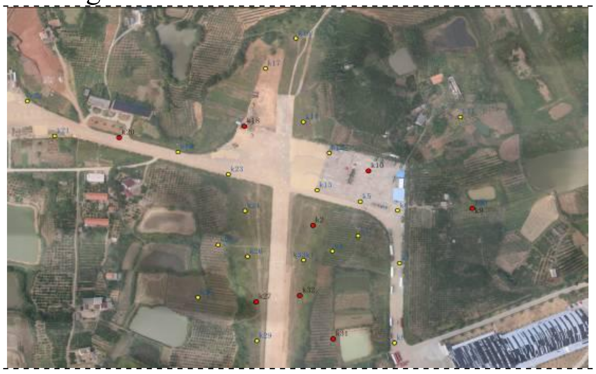

Figure 8. The image of control points (Yellow points are control points, red are check point.).

It is in accord with the requirements of 1:500 mapping that the plane RMSE is 0.05m and the height RMSE is 0.074m. The precisions of control points are shown in Tab.4. The precisions of check points are shown in Tab.5.

Table 4. The precision of control points(Unit:meter)

NO.	X	Y	Z	X Error	Y Error	Z Error
k1	3000.01	3000.02	59.99	-0.0352	-0.0173	0.0061
k3	3033.51	3012.01	59.95	-0.0184	-0.0011	0.0086
k4	3063.33	3032.51	59.32	-0.0428	-0.0150	-0.0111
k5	3065.91	3078.20	59.39	-0.0517	0.0072	-0.0381
k6	3109.16	3066.37	59.19	0.0154	0.0194	-0.0208
k7	3111.44	2995.97	58.11	-0.0583	0.0402	0.0019
k8	3105.74	2889.45	56.38	0.0629	0.1987	-0.2547
k11	3182.33	3191.10	52.43	-0.0505	0.0475	0.0469
k12	3029.79	3143.15	59.46	0.0171	-0.0223	0.0250
k13	3015.58	3093.41	59.71	-0.0054	-0.0154	0.0202
k14	2999.62	3184.47	59.87	-0.0299	-0.0048	-0.0256
k16	2990.93	3296.19	60.83	0.0667	-0.0508	0.0160
k17	2955.62	3255.85	60.54	0.0424	-0.0026	0.0035
k19	2854.05	3144.25	58.95	0.0540	0.0117	-0.0721
k21	2710.51	3165.81	55.72	-0.0783	0.0328	-0.0405
k22	2678.65	3212.28	55.16	-0.0150	0.0574	0.1011
k23	2912.38	3114.61	60.23	0.0940	0.0248	-0.1524
k24	2931.78	3065.86	60.36	0.0544	0.0123	-0.0203
k25	2900.63	3020.43	58.19	0.0287	-0.0230	-0.0528
k26	2934.79	3004.88	59.88	0.0266	-0.0372	0.0087
k28	2877.04	2950.11	52.17	0.0282	-0.0295	-0.0887
k29	2945.67	2892.15	59.75	0.0472	-0.0347	-0.0016
k33	3000.02	3000.02	59.99	-0.0440	-0.0257	0.0731
RMSE				0.0500	0.0500	0.0740

Table 5. The precision of cheak points (Unit: meter)

NO.	X	Y	Z	X Error	Y Error	Z Error
k2	3010.89	3046.29	60.49	0.049	-0.008	-0.024
k10	3075.36	3119.16	59.24	-0.106	0.014	-0.028
k15	3003.57	3233.05	60.45	-0.100	-0.056	-0.078
k20	2785.51	3163.52	57.42	-0.089	-0.030	0.025
k32	2995.55	2952.70	59.96	-0.020	-0.024	-0.057
k31	3034.22	2894.64	55.32	0.132	0.054	-0.028
RMSE：				0.099	0.039	0.049

6. Conclusions

In this paper, a developed unmanned aerial system is introduced, including flight platform, flight control system, four-combined wide-angle camera and MAP-AT data processing software. It is demonstrated by the test in Hubei Province that this system could carry out 1:500-scale aerial triangulation. This low-altitude aerial photogrammetric system meets the requirements of 1:500-scale aerial triangulation according to working condition of the platform, quality of image data, and data processing report. UAVS for low altitude aerial photogrammetry can be applied to aerial photogrammetry, and is a promising method for fine surveying and mapping.

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