

Study on Construction of 3D Topography by UAV-Based Images

Yun-Yao Chi, Chieh-Kai Tsai, Dai-Ling Li

Abstract—In this paper, a method of fast 3D topography modeling using the high-resolution camera images is studied based on the characteristics of Unmanned Aerial Vehicle (UAV) system for low altitude aerial photogrammetry and the need of three dimensional (3D) urban landscape modeling. Firstly, the existing high-resolution digital camera with special design of overlap images is designed by reconstructing and analyzing the auto-flying paths of UAVs, which improves the self-calibration function to achieve the high precision imaging by software, and further increased the resolution of the imaging system. Secondly, several-angle images including vertical images and oblique images gotten by the UAV system are used for the detail measure of urban land surfaces and the texture extraction. Finally, the aerial photography and 3D topography construction are both developed in campus of Chang-Jung University and in Guerin district area in Tainan, Taiwan, provide authentication model for construction of 3D topography based on combined UAV-based camera images from system. The results demonstrated that the UAV system for low altitude aerial photogrammetry can be used in the construction of 3D topography production, and the technology solution in this paper offers a new, fast, and technical plan for the 3D expression of the city landscape, fine modeling and visualization.

Keywords—3D, topography, UAV, images.

I. INTRODUCTION

UAVs are highly mobile, safe and inexpensive, making it easy to get extremely high ground-resolution images. First appeared of UAVs is in 1917, mainly used for military purposes, and later gradually used in combat, reconnaissance and civilian telemetry flight platform. Unmanned aircraft is combined with positioning navigation system, automatic flight control, real-time imaging, wireless communication systems and a variety of sensors and other modules at the same time, making the collection and investigation of space data more convenient and fast [1]. Multi-rotor UAVs have excellent low-altitude fixed-point spin-off stability free from the impact of cloud coverage, and they help to achieve high-resolution mobile video quality [2].

In view of UASs' applications, it enhances the efficiency of on-site investigation. This paper explored the reliability of aerial imaging and 3D data production via multi-axis UAVs. Orthorectification is the process of reducing the geometric error inherent in a photo. Orthorectification is produced using raw numerical images, numerical surface model (DSM) and aerial

triangulation data, but DSM data are difficult to obtain. In order to effectively analyze the accuracy of planar orthophotos and DSM data, this study will respectively confirm the error values by the distance values measured on the ground and the distance values on the orthophoto images produced. The 3D laser scanner, Light Detection and Ranging (LiDAR), and its point cloud analysis are the devices and technologies most commonly used in 3D models [3]. Although ground LiDAR and airborne LiDAR have been widely used in 3D modeling, they are limited to very high costs and cannot be widely applied in the general fields [4].

In this paper, a multi-rotor UAV aerial with high-resolution camera was used both in campus of Chang-Jung University and in Guerin district of Tainan city in Taiwan and collocated with a number of ground control points (as Fig. 1). The rectification and aerial triangulation were used to analyze and compare the accuracy of stereoscopic and DSM data (3D topography) based on combined UAV-based camera images from system. The UAV air space mission should be subject to regional airspace control, air space survey mission in the study area to avoid the no navigation area.

II. REVIEWS

Giordan et al. [5] pointed out that the recent development of UAVs has increased the number of technical solutions available for monitoring and mapping. UAVs is generally cheaper and more versatile than traditional remote sensing techniques, so they can be considered ideal for acquiring images and other physical parameters before, during, and after natural disaster events. This is an important to add value, especially for small areas (several square kilometers).

Lucieer et al. [6] used UAVs to capture the micro-topography of the Antarctic moss beds, which collected low-altitude aerial photography using a small multi-rotor UAV and calculated visual technology using Structure from Motion (SfM). The multi-view aerial photography derives the super-high-resolution 3D model. From the 3D model and aerial photographs, a 2-mm digital surface model and a 1-mm orthophoto mosaic are obtained, respectively. The result shows the DSM geometry accuracy is equal to 4 mm.

Turner et al. [7] used the SfM technology to obtain accurate orthophoto mosaic, 1cm resolution, 10cm absolute geometry from a multi-rotor UAV and the accuracy of point cloud obtained from the SfM in the coastal erosion study.

Harwin and Lucieer [8] achieved absolute accuracy between 25-40 mm using a multi-rotor UAV flying at 40 meters (AGL) above ground level. With the recent rollout of commercial packages such as AgisoftPhotoscan1 and Pix4D, as well as the

Y. Y. Chi is with the Department of Land Management and Development, Chang Jung Christian University, No.1 Changda Road, Guiren District, Tainan City, Taiwan (corresponding author, phone: 886-06-2785123; fax: 886-06-2785902; e-mail: yunyao@mail.cjcu.edu.tw).

C. K. Tsai and D. L. Li., are both with the Department of Land Management and Development, Chang Jung Christian University, Tainan, Taiwan (e-mail: r6663049@mailst.cjcu.edu.tw).

increase in drone capabilities (CPUs and GPUs), the SfM approach will be easier for UAVs' users.

III. METHODOLOGY

In this study, the UAV platform used is a multi-rotor DJI P4P (as Fig. 2). The camera is equipped with a 1-inch, 20-megapixel sensor capable of shooting 4 K/60fps video and taking still photos at 14 frames per second. Flight Autonomy system adds rear vision sensors and infrared sensors on both sides of the fuselage. In the visual system, DJI P4P more forward-looking vision system, rear view system, down the visual system, contribute to flight safety, so the final choice is DJI P4P as a platform of this study.

Firstly, the existing high-resolution digital camera with special design of overlap images designed by reconstructing and analyzing the auto-flying paths of UAVs, which improves the self-calibration function to achieve the high precision imaging by software, and further increased the resolution of the imaging system. Secondly, several-angle images including vertical images and oblique images gotten by the UAV system are used for the detail measurement of urban land surfaces and the texture extraction. Finally, the aerial photography and 3D

topography construction both developed in campus of Chang-Jung University and in Guerin district area in Tainan, Taiwan, provide authentication model for construction of 3D topography based on combined UAV-based camera images from system. The research steps of this paper are as follows:

- (1) We must correct the attitude of DJI P4P to get the correct difference between the air and the ground. In this way, we can find out the difference between various orthophotos and 3D modeling.
- (2) The orthophotos and distance measurements are obtained via Pix4D and ArcGIS software. The comparisons of the actual distance (or area) and the ones by global coordinates calculated are developed. The actual distance and area are measured precisely using a total station for traditional traverse surveying. We can calculate the errors of distances (or area).
- (3) Use Pix4D's 3D surround function for shooting objects, and then put the image into Pix4D for 3D modeling processing. Then, we use the Autodesk Application Manager to open the file, which can use the point cloud to calculate the volume, but still need to consider the above errors.

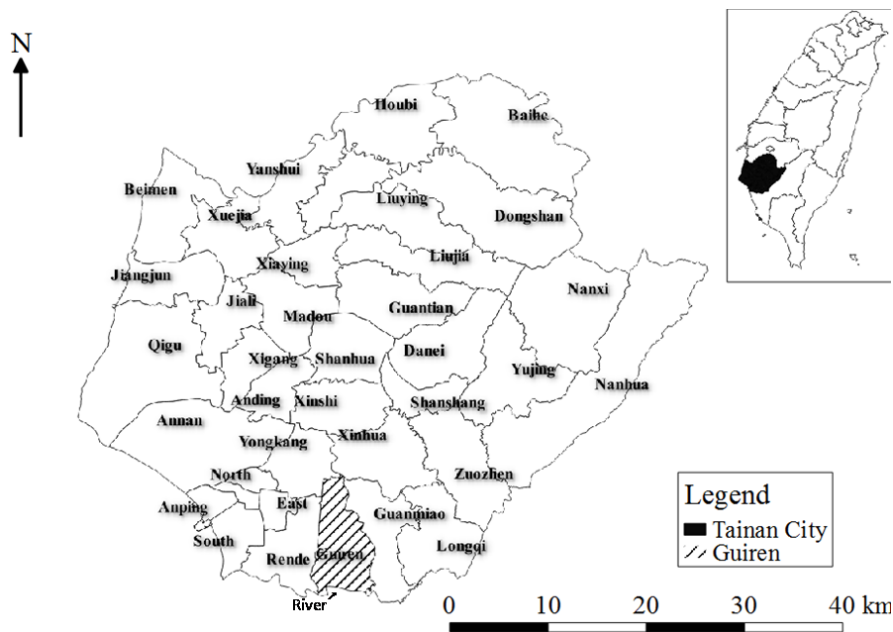


Fig. 1 Location map of the research area in this paper



Fig. 2 Photo of the DJI P4P UAVs [9]

IV. RESULTS

A. Instrument Correction

There are four ground control points sited on the ground. Firstly, we use the traverse surveying method to measure the angles of outside corners and side lengths (distances) of the quadrilateral enclosed (ABCD), as shown in Fig. 3. The flying height of drones is 60 m above the ground, and the overlap rate before and after the image is 70%. Secondly, we use the adjustment method of closed traverse surveying to calculate the coordinates of each point, and then to calculate the distance and

area from the coordinates. We set the accuracy of the closed traverse surveying above 0.05%. Table I shows the results of comparison of UAV photograph distances and areas. In Table I, the measurement and calculation results of the closed traverse surveying are shown, and the accuracy of the quadrilateral enclosed (ratio of closure) is $0.045\% < 0.05\%$.

The precision of the distances displayed in Table I is between 0.85-1.31 percent, the average value is 0.98%, and the area accuracy is approach to 0.90%, although we calculated the area accuracy is 1.39% by the law of error propagation. It shows that the accuracy of the distance and area of the UAV-based orthophotos obtained in this study is about 1% and 1.4%, individually. Fig. 4 shows the comparison of control points for UAV-based image and Google map. The comparison shows that the two locations are in perfect agreement, and UAV's photo resolution is better than that of Google.

B. Topography

Figs. 5 and 6 are the orthophoto maps of streets in Guerin district and the rivers adjacent to Chang-Jung University, respectively. These maps are photos taken by the UAVs in this paper, made using Pix4D software. From these orthophotos, topographic maps had developed, including streets, houses, playgrounds, and natural rivers. Provide valuable terrain information for the natural shape of the river. Through these orthophotos, we can obtain high-precision topography, and the distance and area between the points.

C. 3D Modeling

In this study, we use the GPS and IMU modules to perform aerial photography to obtain orthographic images. Therefore, the photos were taken with the attitude, GPS coordinates, and camera angles of the drone at the time of shooting. The orthorectified image and DSM data with different resolutions and coordinate data analyzed by the Pix4D software. Fig. 7 shows the result of 3D modeling for a structure in Guerin district in Tainan. Fig. 8 shows the result of DSM for the structure in Guerin district in Tainan. In the future, this study will carry out points in the survey area that have the same coordinate position as the DSM data to compare the error between the two to analyze the reliability of the DSM data produced by this institute.

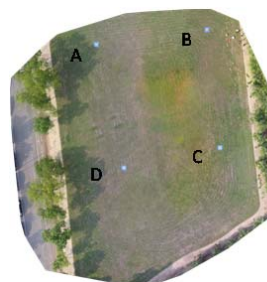


Fig. 3 Locations of the control points for UAVs' image correction

TABLE I
COMPARISONS FOR ACCURACY OF UAV-BASED MEASURES

Points	Horizontal angles*		Distance* (m)	Distance (m)	Error (cm)	Accuracy (%)
	Normal position	Inverted position	(1)	By AV-based (2)		
A	274°58'48"	94°59'06"	27.667	27.304	-3.63	1.31
B	271°17'19"	91°17'55"	29.272	29.022	-2.50	0.85
C	264°24'23"	84°22'23"	24.320	24.114	-2.06	0.85
D	269°17'59"	89°15'58"	31.186	30.905	-2.81	0.90
Area of ABCD (m ²)			784.04	776.74	-7.30	0.93

Remark*: obtained by traverse surveying, ratio of closure = 4.05×10^{-4}



Fig. 4 Comparison of UAV-based image and Google maps



Fig. 5 Orthophoto of the streets in Guerin district via UAVs



Fig. 6 Orthophoto of river near Chang-Jung University via UAVs



Fig. 7 3D modeling of structure in Guerin district via UAVs images

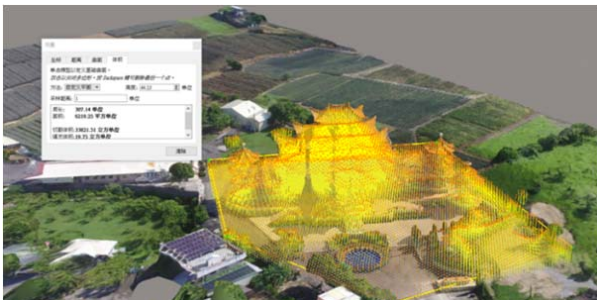


Fig. 8 Numerical surface model calculating via UAVs images

V. CONCLUSION

In this study, we obtained the UAVs-based aerial photography together with ground control points in the research area, and using Pix4D processing to obtain orthophotos and DSM data. The accuracy analysis and comparison of the data of orthophotogrammetry and actual traverse surveying results yields the following conclusions:

- (1) The accuracy of the distance and area of the UAV-based orthophotos obtained in this study is about 1% and 1.4%, individually.
- (2) High accuracy topographic maps had developed by the UAVs-based orthophotos, including streets, houses, playgrounds, and natural rivers. We provide valuable terrain information for the natural shape of the river. Through these orthophotos, we can obtain high-precision

distance and area between points.

- (3) We obtained the result of 3D modeling and DSM for a structure in Guerin district in Tainan.

The results obtained in this study show that using UAVs-based photographs by high-resolution camera can obtain very high-precision distance and 3D model measurements, and the cost is only one thousandth of LiDAR, and the future can continue to be studied in this regard.

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