Application and Typical Case of Unmanned Aerial Vehicles Combined with Building 3D Modeling

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Abstract. With the development of unmanned aerial vehicle (UAV) technology, the application of UAV in building 3D modeling is becoming more and more extensive, including the application of UAV in building 3D modeling. This paper introduces the composition of commonly used related equipment and some key UAV technologies combined with building 3D modeling: 3D laser scanning technology, Photogrammetry, Multi-view 3D reconstruction technology and Seismic disaster prevention technology. This paper also studies practical applications and related cases. On the one hand, UAV can be used in the protection of ancient building heritage. Combined with photography, measurement, modeling technology, UAVs can rapid and efficient access to relevant building three-dimensional information, including building damage and overall configuration, then provide important information and reference for building heritage protection. On the other hand, UAVs can also carry out multi-faceted evaluation and survey of modern buildings, collect topography, guide seismic planning and post-disaster reconstruction, and save project costs.

Keywords: Architecture, 3D model of the real scene, UAV, key technology, typical case.

1. Introduction

The rapid and accurate modeling of existing buildings is of great significance to protecting ancient architectural heritage and seismic disaster prevention. Simultaneously, the traditional surveying and mapping methods need to use more professional surveying and mapping tools and workforce and material resources. Moreover, they are easy to cause secondary damage to the ancient architectural heritage, with significant limitations. With unmanned aerial vehicle (UAV) photography technology, a wide range of building image information can be obtained quickly and efficiently, which dramatically improves the efficiency of building surveying and mapping and reduces the cost. UAVs can carry various sensors to reach places that are usually difficult to reach and obtain images from different angles of view.

The remainder of the paper is as follows. In section 2, the compositions of the UAV system are presented. Section 3 introduces critical technology of UAVs. Section 4 provides some application and typical cases, including applying in architectural heritage protection, guiding seismic planning and construction operations. In section 5, some conclusions are presented.
2. Composition of the UAV System

The UAV system for aerial photography and architectural heritage modeling can be divided into these parts: UAV platform, ground support equipment, other ground equipment, mount, and corresponding software.

UAV platforms can be mainly divided into three categories: multi-rotor UAV, fixed-wing UAV, and balloon, in which multi-rotor UAV has broad coverage, can hover, and can move in multiple moving directions in the air, so it is most suitable for aerial photography[1]. A multi-rotor UAV consists of a motor, a blade, a connecting rod, a core part of the fuselage, and a landing gear. The mount is often arranged in the landing gear through an electronic stabilized cloud head, and the related circuits are often arranged in the core part of the fuselage. Some UAVs are also equipped with LED signal lights to help flight personnel identify the status. According to the mission requirements of UAV, the electrical equipment in the core part of the fuselage is also different. The basic flight control system of UAV is battery and flight control system. The flight control system is based on multi-task high-speed computing chip, including signal transceiver, sensor, processor, controller, and software. The UAV used for aerial photography needs GPS signal antenna and circuit, digital image transmission system circuit and so on. As a flight platform, UAVs can carry various loads, such as honeycomb space UAVs can carry various equipment, including lidar, ultraviolet imager, tilt camera, gas detector, and photoelectric pod, as shown in figure 1.

![Figure 1. HC-332 hybrid UAV with multiple loads[2].](image)

Flight ground support equipment is mainly to assist, control, communication, and path planning of UAV during flight. The commonly used equipment is the remote control, and also includes computers equipped with related software and transceiver equipment.

Other ground equipment is mainly for pre-flight planning and processing. Pre-flight processing mainly includes track planning, flight planning, test equipment, etc. After flight, the data or images taken need to be processed to obtain the final model. The related parts are mainly based on various computer platform software, including image processing, image modeling and so on.

The mount part is mainly photographic camera or a variety of remote sensing equipment. The remote sensing equipment for building measurement includes 3D lidar, microwave radar remote sensing, thermal imaging camera and so on. 3D lidar, which integrates laser scanning and positioning, does not need other illumination conditions, does not need contact with the object under test, and is conducive to modeling. However, the instrument's price is higher, which puts forward higher requirements[3] for the result processing software. Microwave radar remote sensing technology is relatively mature, not affected by clouds and rain, can penetrate fine particles of dry sediments, and can obtain surface soil characteristics, and has a unique advantage in detecting hidden architectural sites on the shallow surface. The ancient river[4] in the Sahara Desert of Africa was discovered by microwave remote sensing. The thermal imaging camera has excellent advantages in architectural heritage archaeology with severe damage by using different imaging rates of material heating and cooling. The digital camera is used as the acquisition tool for photogrammetry to obtain the position, size, and shape of the target. It is low cost and high efficiency. It is widely used in photogrammetry.
3. Key Technologies

3.1. 3D Laser Scanning Technology
The 3D laser scanning technology is also called the real scene replication technology. Through high-speed laser scanning and measurement, the 3D coordinate data on the measured object's surface can be obtained quickly and quickly. For smaller and complex single buildings or 3D laser scanning, the mapping efficiency of building monomers and small building groups has been much higher than that of traditional manual measurement. Because the laser can penetrate the water body and crown gap, it has great advantages in examining understory or underwater sites. However, the speed of collecting data is slower than that of the optical acquisition method, the workload is large, and the large-scale acquisition is difficult[4]. It still has some limitations for surveying and mapping of the spatial environment in an extensive range similar to historic urban areas and traditional villages. Because of the massive distortion of the image obtained by attitude instability in UAV aerial photography, the traditional aerial photogrammetry data processing software takes a long time, but the new processing software Agisoft Photoscan greatly improve this problem.

3.2. Photogrammetry
It refers to the technology of measuring the shape, size, and spatial position of the target object by combining an optical camera and film. The spatial information of the larger area can be obtained quickly and efficiently utilizing the digital camera and other equipment. The spatial size of the object in the scene can be measured by more than two photos of the same scene at different angles. As for UAV, UAV low altitude photogrammetry technology is used to obtain high-resolution digital images, UAV as flight platform, high-resolution digital camera as a sensor, and integrated application in the system through GNSS, IMU and other technologies. Finally, obtain small area, correct color, high-resolution photogrammetry data. Because UAV is used as the platform, the flight altitude is low, which has the advantages of obtaining the high-resolution image, relatively low cost, simple operation, no airport, short period, high efficiency, and reducing the efficiency of fieldwork. Simultaneously, it also includes tilt photogrammetry technology, through multi-angle shooting to obtain different angles of the same object tilt image, to obtain the traditional aerial photogrammetry can not obtain the side texture of the building. Simultaneously, the image data can be collected from 5 different angles, such as one positive photograph and four inclines. By collecting images from different angles, tilt photogrammetry technology can better display the object's side (building facade) while establishing the three-dimensional model of the scene. It can not only obtain the front image information but also obtain the multi-side image information of the ground object. It has been widely used in digital city construction, emergency command, homeland security, and urban management. Compared with traditional aerial photography, the image has a changing proportion, and there will be defects in the high ground object blocking the low ground object. Generally, more photos are needed for stitching. For only orthophoto (total plane), at least 30% repetition is required between the two photos, and if a 3D model needs to be established, it is best to have more than 50% repetition[5]. The photo splicing technology can be combined with UAV technology to reduce flight altitude and increase heading and lateral overlap to meet high precision requirements and refinement of cultural heritage. Before flight measurement, route formulation is carried out in advance according to flight range and image requirements. As shown in figure 2, good route planning can consider the time and cost of flight operations and the overall quality of images taken. Lay a good foundation for photography.
Figure 2. Pre-flight scoping and route planning.

It should be pointed out that the photogrammetry technology level based on the UAV platform requires the camera, lens, and platform to cooperate in order to achieve better results. Simultaneously, photogrammetry technology needs to be combined with photographic modeling technology to obtain the final model.

3.3. Multi-view 3D Reconstruction Technology

Multi-view reconstruction is a method to restore the scene 3D model using different view images of multiple scenes. It is generally necessary to combine the image itself with the shooting position. According to the latest multi-view 3D reconstruction technology, any photo can be processed[6]. Moreover, no control point, and through the control point can generate a real coordinate of the three-dimensional model. A variety of shooting positions and images can be selected, including aerial photographs and high-resolution digital cameras, to realize image orientation and 3D model reconstruction automatically.

3.4. Seismic Disaster Prevention Technology

Seismic disaster prevention technology includes intelligent classification of buildings, seismic disaster prevention planning model, seismic disaster prevention planning information system management, seismic risk analysis, disaster prediction and assessment, auxiliary planning and design, planning management, disaster reduction response planning and management, covering the whole process of disaster prediction, economic loss estimation to a planning scheme, disaster reduction countermeasures, etc. In the data processing and utilization stage after UAV photogrammetry and 3D modeling, the obtained building information can be effectively transformed into concrete schemes that can guide seismic prevention and building protection. Combined with UAV technology, the old buildings, and ancient buildings are effectively supervised to strengthen the weakest link of seismic disaster prevention. For example, the seismic evaluation model can evaluate the seismic capacity of the building according to the potential damage degree of the building and comprehensively evaluate the overall seismic capacity of the building group through the full probability seismic capacity index, seismic risk analysis, group building vulnerability analysis, as shown in figure 3: additional planning scheme optimization and emergency decision optimization.
4. Applications and Typical Cases

Compared with the traditional surveying and mapping method, the most significant advantage of UAV is to realize low cost, wide range, multi-angle and high-efficiency building image acquisition and can combine relevant professional software and information technology to establish an acceptable three-dimensional model to provide building data.

At present, there are many UAVs and ancient architectural heritage mapping, modeling, and protection of comprehensive research. Sui Zhengsu et al. used ASCITE Falcon 8 UAV to map the elevation of the Great Wall section. The route planning and design used ASCITEC Navigator software and DEM( digital elevation model) to adjust the altitude to avoid a collision, used total station polar coordinate method to collect three-dimensional coordinates of image control points, used Agisoft PhotoScan software to automatically extract image connection points, image control point measurement, adjustment calculation, and generated three-dimensional dense point cloud. Afterimage uniform color, elevation image correction, and processing, the elevation image map[8] was generated.

Yao Rui and others combined UAV measurement technology and BIM technology to establish the ancient building model of Baishikou Shuangta. After flight planning, aerial photography, point cloud data filtering, and conversion, the model was established using Revit software and based on grass touch, the construction[9] of the complex was completed. Li Ming et al. established a three-dimensional model of Wangjia Garden Palace (Angkor Archaeological relics) by combining banded tilt aerial photography with circular tilt aerial photography and commercial Smart-3D software to process aerial data, High precision 3D model, and texture mapping. The plane position error and the elevation error of the internal encryption point to the nearby field control point meet the accuracy requirement[5] 1:500 topographic map. Fu Li and others used Dajiang Inspire 1 UAV to survey and survey the ancient brick tower building (Wuhua Temple Tower, Yiyang, Henan Province). The earth remains (the north wall of Nanton old city, Using Altizure software to plan routes and Agisoft PhotoScan software to generate dense point cloud, mesh, texture gradually, set control points, To determine the damage of the Wuhua Temple Tower, the settlement of the foundation and the tilt of the tower, The digital surface elevation model of North city wall is derived, For wall maintenance and reinforcement design[6].

UAV aerial photography can also be integrated into other ways to improve overall and local accuracy. Yu Xuefei combines the ground 3D laser scanning point cloud data model and UAV low-altitude close-range photogrammetry to obtain digital image information, realizes the present situation mapping of Tongzhou lighting tower in Beijing, integrates open space data, and realizes the joint supplement of 3D data. According to the 3D data measurement scale manual reconstruction and TIN model, the acceptable 3D model of lamp tower structure is constructed. The protective research of ancient tower is carried out through multi-source digital mapping technology and multi-disciplinary cross-fusion to assist the tower to realize repair design, disease expression, cultural display, and virtual restoration[10]. Xie Yunpeng and others used ground lidar technology (Leica BLK360 laser scanner)
to make up for the defects of the 3D model local texture fuzzy distortion and ground object cavity caused by optical occlusion and transmission in UAV tilt photography. Manual coarse registration and ICP point cloud matching algorithm were used to realize data registration and fusion modeling, which improved the texture accuracy and texture detail[11] of the model. Combined with UAV modeling and mapping of ancient buildings not only stays in the level of scientific research but also gradually develops into practical and mature technology. The Land and Resources Bureau of Yangxian County, Shanxi Province," Land UAV Project team "model the local enlightened temple Sherita, and get a more accurate and accurate three-dimensional data model, which can be used to establish health files to study the deformation, settlement, wind and rain erosion of ancient buildings, and can also be used to print models d make virtual building[12]. Moreover, given the protection and research of the material and cultural heritage of Yuansheng Palace in Shunyi District, combining with Dajiang Mavic UAV and the obtained pos data, it provides orthophoto material for smart3D modeling. The front hall, the central hall, rear hall, lidar scanning modeling, rapid and accurate millimeter 3D model[13]. According to the application of rural cadastral survey, Qishan County, Baoji City, Shaanxi Province, verifies the tilt photogrammetry technology of image-free UAV, realizes coordinate conversion based on vectorized mapping and feature points of ground objects. The time and cost[14] of measurement are reduced. Building 3D models are not only often used in the field of ancient building protection but also of great significance to seismic disaster prevention and post-disaster disposal and can be provided as information data for other related applications. The acceptable 3D solid model with high precision can provide a sufficient basis for the relevant units responsible for geological disaster loss assessment and post-disaster reconstruction and greatly improve the working efficiency. At the same time, it can also be used as the historical basis of demolition office in the early stage of demolition to prevent some people from building illegally because of the reason of compensation for demolition. It can also improve the effective factual basis and facilitate civil disputes and resettlement for some people who have doubts about the building area and are dissatisfied with the compensation. The fine 3D solid model with high precision is shown in figure 4 and figure 5. This kind of model can not only represent the structural layout of the building in a wide range but also record the close-range details of the building.
The high precision real scene 3D model can measure the area, length, latitude and longitude, elevation, and other information on the model, as shown in figure 6. It can be used in the stage of engineering planning, design, and review, to facilitate on-site survey and fully understand the construction area and surrounding environment. During the construction period, the area, volume, vegetation coverage, project schedule, and existing landforms can be surveyed and measured by UAV photogrammetry to provide a reliable basis for environmental protection departments. Photogrammetry technology provides accurate and comprehensive texture details for urban and rural planning, which is convenient for design and construction, effectively avoids reconstruction work, and shortens construction time. For example, the cultivated land is monitored irregularly, and the 3D model of the real scene is established by photogrammetry. As shown in figure 7, it can be surveyed and delimited to effectively protect arable land resources, such as illegal building renovation.
carry out excavation and transportation analysis and refinement of earth and rock. Therefore, it can save time for dispute resolution and play an essential role in project cost control.

Figure 8. Calculation of earthwork of high precision 3D real scene model.

Besides, we can make full use of the characteristics of low cost, fast speed, and a wide range of aerial photography UAV. Through multiple UAV flights, the planning land is collected regularly, and the construction progress is supervised, as shown in figure 9. At the same time, it intuitively reflects the effect before and after construction. After the construction is finished, a new 3D model of the real scene is established to collect the topography and geomorphology of the surrounding environment and the planned area and to achieve a pleasing effect display.

Figure 9. High-precision 3D Model Building Area Measurement.

An example of the combination of UAV aerial photography and seismic disaster prevention is an aerial photograph of seismic disaster prevention planning for Yongping County, Dali, combined with tilt photography, about 2.4 square kilometers in Yongping county, establish a complete regional database of building information, systematic analysis of earthquake resistance, carry out seismic planning. Flying platform with sprite 4 Rtk multi-rotor drone, complete 3D model building by smart3D software, complete the whole design, photography, PMVS algorithm matching, white film generation, texture mapping to 3D model construction, accuracy evaluation. Its image and a three-dimensional model of ancient architecture are shown in figure 10 and figure 11. Accuracy of orthophoto is less than 10 cm, The accuracy error of area calculation is less than 0.3%, can transform each other in WGS84, Xi'an 80, Beijing 54 coordinate system; The accuracy plane error of 3D model is less than 15 cm, Elevation accuracy less than 20 cm. The accuracy error of the volume calculation is less than 0.5. To monomerize regional buildings, combined with the architectural BIM model, used for disaster model deduction, disaster relief preview and so on. Three-dimensional models built by drones. The information base of seismic disaster prevention is constructed by matching the information base based on the model.
5. Conclusion

UAV technology with photogrammetry and 3D reconstruction technology brings new technical support for efficient acquisition of building information. Compared with the traditional manual measurement, UAV photography has high efficiency, low cost, and wide range. It can quickly build a three-dimensional model of architecture and improve the breadth and depth of application through the combination of various equipment and technology. It is of great significance in cultural heritage protection, earthquake prevention and disaster resistance, construction project management and so on.

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