Construction and Analysis of 3D Scene Model of Landscape Space Based on UAV Oblique Photography and 3D Laser Scanner

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Abstract: How to accurately describe landscapes spatial features and construct the 3D real-scene model is a new topic in the field of digital landscape. The maturity of UAV oblique photography and 3D laser scanning technology has brought new opportunities for the digitalization of landscapes. In this paper, UAV oblique photographic equipment and Smart3Dcapture 3D modelling software were used for 3D real-scene modelling of existing sites. Data mending was performed for the near surface layer space in key section using a 3D laser scanner, to generate a comprehensive spatial 3D model of data and achieve precise spatial cognition. Qingliang Mountain Park in Nanjing was taken as an example to extract and analyse landscape spatial features from three aspects of data acquisition-modelling-spatial analysis. The feasibility of applying UAV oblique photography technology and 3D laser scanning technology in 3D real-scene modelling of small to medium scale landscape architectures was verified by this study, and a set of research methods for site modelling and cognition was constructed.

Keywords: Unmanned Aerial Vehicle (UAV), oblique photography, 3D laser scanning, 3D scene modelling

1 Introduction

Landscape site own the feature of complexity. How to achieve refined modelling and precise representation of a site and present the characteristics of the landscape more intuitively are new research hotspots in the field of landscape design. In existing modelling methods, the 3D model establishes 3D cubes through CAD 2-dimensional information. The texture is applied by specialized 3D software, with relatively heavy workload, long modelling period, and varying degrees of precision. The 3D reconstruction based on laser scanning system includes airborne laser scanning, vehicle-borne laser scanning and terrestrial laser scanning (LI JIAZHONG et al. 2017). This kind of technology acquires data with high speed and high precision but also has large data sizes, hence it is suitable for small-scale landscape research. The oblique photography technology is a new technology developed in the field of international surveying and mapping in recent years. It acquires multidirectional high-resolution images by using UAV equipped with cameras to generate a 3D model with real texture and high precision. The technology processes data blocks and can handle large-scale site data. The oblique photography technology has changed the limitations of previous aerial remote sensing images, which can only be photographed in the vertical direction. Comprehensive information of landscapes are acquired from multiple angles, which has met the current needs of precision modelling. However, as the oblique photography technology is limited by flight altitude and complex vegetation topographic conditions, it is often impossible to conduct precise modelling for areas beneath the forest canopy and models are prone to form blind areas in data acquisition. Therefore, the oblique photography technology and 3D laser scanning technology were combined in this study.

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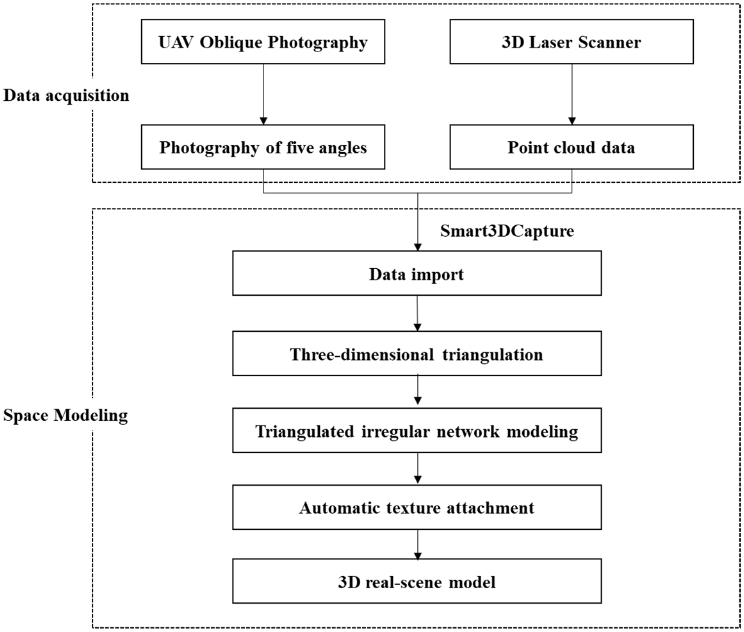

Fig. 1: Operating process

First, the overall site spatial data was obtained through UAV oblique photography. Then data mending was performed for the under-canopy space in key segments using ground site 3D laser scanning data, so as to obtain comprehensive and complete 3D information. On this basis, with the aid of Smart3DCaputre software, the spatial three-dimensional model is established through the steps of three-dimensional triangulation, triangulated irregular network modelling and automatic texture mapping. (Fig. 1) Qingliang Mountain Park was taken as the measurement object to establish the 3D real-scene model in the study. The purpose of the study was to explore the possibility of synergetic application of UAV oblique photography technology and 3D laser scanning technology in landscape spatial modelling. Next, refined analysis and precise modelling of the research site were implemented. Finally, collection, storage, management, analysis and visualization of landscape spatial information were implemented to provide support for the subsequent evaluation and analysis of landscape space.

2 Data Acquisition

2.1 Research Site

Qingliang Mountain Park is located in Gulou District, Nanjing City, stretching to Guangzhou Road in the south, Hujuguan Road in the east, Huju Road in the west, park internal roads and ridgelines in the north. Covering an area of 12.25 hectares, it is an urban leisure park at present, with relatively mature greening, roads and infrastructure in the park. The park is densely covered with vegetation with a relatively high canopy density. In this study, site precise modelling was performed using 3D model to describe and analyse the existing spatial features as the basic materials for later renovation and upgrading of the park.

2.2 Data Acquisition of UAV Oblique Photography System

UAV oblique photogrammetric system consists of unmanned flight platform system, flight navigation and control system, photographic equipment, data transmission system, ground monitoring system, etc. There are many kinds of flight platform systems. The choice of platform for a photogrammetric mission is affected by the object area type, size and location, required accuracy, available funds, photogrammetric processing chain and the end-product (NURMINEN 2015). A rotary UAV flight platform equipped with a stabilization platform and a five lens oblique camera is used in in this study (Fig. 2). UAV feature manoeuvrability, flexibility, speediness, economy, etc. High quality and high-resolution images could be obtained quickly and efficiently with UAV as the photographic platform. The advantages of a UAV in photogrammetry were unparalleled by traditional satellite remote sensing (YANG GUODONG et al. 2016), which also made it possible to apply the UAV oblique photography in small and medium scale landscape studies. By equipping a five-lens camera on the same UAV flight platform, it is possible to acquire images from five different angles simultaneously, i. e. one vertical angle and four oblique angles, to obtain texture information and geometric information of the ground object elevation not available by conventional photography. The UAV automatically recorded the photo space position and angle posture through GPS and INS (Inertial Navigation System) when shooting in the air. Traditional aerial photogrammetric technology could only obtain information featured on top of ground objects, while the available information on detailed profile and texture of the side of ground objects was very limited. Compared with the vertically photographed image obtained by traditional aerial photography, oblique photogrammetric technology acquired the architecture data from different angles by carrying multiple sensors to quickly and efficiently obtain high-resolution texture information on the top and side of the architecture.

Fig. 2:
UAV platform with five lens cameras

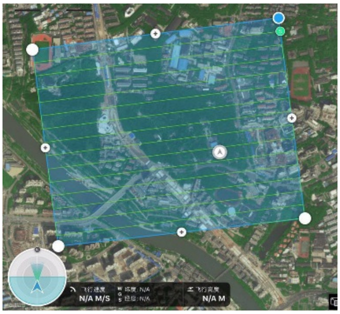

Fig. 3:
The flight route

Fig. 4:
FARO330 3D laser scanner

The southern area of Qingliang Mountain Park was selected as the test area for data acquisition. Photographing range: Longitude E118°45′35.19″ ~ E118°45′7.04″, latitude N32°02′ 58.50″ ~ N32°03′13.95″, aerial photogenic area 42 hectares. The terrain conditions in the test area were complex with relatively large vertical changes. Affected by the mountain elevation inside the site and the height of surrounding buildings, the relative flight height of the design was 150m. One sortie was set for the flight, with 13 routes per sortie. Both course overlap and side overlap was 75 %. By pre-setting the flight route in the ground control system (Fig. 3), the flight platform carried the oblique aerial photographic camera to conduct continuous automatic shooting according to the designed route. Five cameras conducted automatic shooting simultaneously and recorded the altitude, exposure time, photographic site coordinates, posture and other information. The flight time was about 35 minutes, with the shooting interval of 1 second. A total of 9,600 photos were obtained by five cameras, with the photo resolution of 42 million pixels.

2.3 Data Acquisition of 3D Laser Scanner

3D laser scanning is a method of measuring, which records the spatial location information of the scanned ground objects in the form of a 3D point cloud through target reflection by continuously rotating and emitting laser (MA GUOCHAO et al. 2017). The image of ground object elements near the ground and point cloud data can be obtained through 3D laser scanning technology, which is supplementary to the point cloud data from the image acquired by the oblique photography. This combination can improve the information of vegetation underforest space and building details, and reduce the data blind spot of the 3D model. In this study, FARO330 standing mobile 3D laser scanner (Fig. 4) was used to conduct ground data mending for Qingliang Mountain Park entrance, main nodes and landscape architecture. Due to the influence of vegetation cover, complete point cloud data could not be obtained through UAV oblique photography for these mending points.

Since UAV oblique photography and ground 3D laser scanning are two sets of relatively independent measurement technology systems, the measurement results have their own independent coordinate system. Each station data in Ground 3D laser scanning have an independent coordinate system. The data point scanned by each station are generally transformed through the targets set in the data overlap area to conduct matrix transformation splicing, achieve 3D point cloud integration, and coordinate unification (WANG LIHUI 2011). To obtain accurate coordinates, target surveillance was required for the measuring point before scanning. Scanning recognition of the three targets was performed to obtain the accurate 3D coordinates of target center, to facilitate the later fusion and matching with the oblique photography data. In this study, the scanning area setting was 360° in the horizontal direction, 155° in the vertical direction, and scanning resolution 10,000 points per circumference.

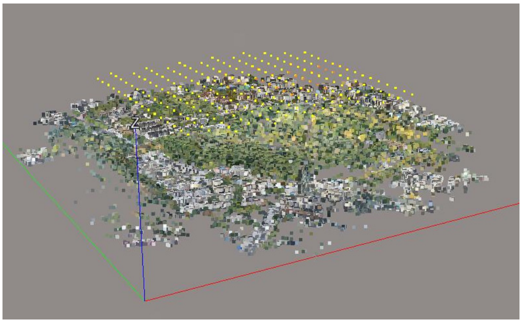

Fig. 5:
Point cloud data

3 Space Modelling

In 3D real-scene modelling, images were processed using Smart3DCapture software of Bentley based on a large number of images and point cloud data obtained by UAV aerial photography and 3D laser scanning. The software generated an ultra-high-density point cloud through stitching continuous images and automatically produced a high-resolution 3D real scene model based on real image texture. Smart3DCapture could meet the needs of simultaneous import of 3D oblique photography data and 3D laser scanning data (Fig. 5), both of which had real 3D coordinates. Moreover, the premise of accurate data fusion was the unity of coordinate systems and the matching of coordinate points. In the 3D reconstruction process of Smart3DCapture, an ultra-high-density 3D point cloud was first generated from the acquired images through the multi-view image intensive matching technology. Next, the point cloud data acquired by 3D laser scanning was integrated. Then, the triangulated irregular network (TIN) with different levels of details was constructed according to the 3D point cloud. Subsequently, a 3D model with blank model was generated by optimizing and simplifying the triangulated network. Finally, the texture information corresponding to the location was extracted automatically and mapped onto the triangular facets of the corresponding model and ultimately generate an urban 3D model with clear and vivid texture. The resulting 3D real-scene model had rich details, which vividly represented the spatial panorama of Qingliang Mountain Park (Fig. 6). The fineness of the section model after 3D laser scanner mending was significantly higher than that of the section without mending. And the details of the under-forest space and building facade were also complete.

In addition, DSM, DOM, DLG and other data results could be exported simultaneously in the 3D model files generated by Smart3DCapture output, which were compatible with obj, osg (osgb), dae, xml and other common formats. The files could be easily imported into various mainstream GIS platforms and 3D editing software.

Fig. 6: 3D model of Qingliang Mountain Park

4 Spatial Model Analysis

The 3D real-scene model of Qingliang Mountain Park generated by UAV oblique photography and Smart3DCapture 3D real-scene modelling technology reflects the spatial characteristics and attributes of the existing park clearly and accurately. The size and shape, height, material color, distance, location and other information of the architecture, vegetation, roads and facilities in Qingliang Mountain Park were all intuitively reflected in the 3D real-scene model. The 3D model outputs were ArcGIS compatible dae format files in the study. The spatial features were analysed by using the ArcGIS software, which provided the basis for later space upgrading and renovation studies.

It could be seen from the 3D real-scene model that Qingliang Mountain was high in the north and low in the south, showing the spatial morphology of "One peak, three ridges and two valleys" as a whole. In the study, six typical sections of mountain peaks, ridges and valleys were selected to dissect the 3D real-scene model, and the cross-section thus obtained could intuitively reflect the mountain surface morphology under the influence of ground objects (Fig. 7). On this basis, the spatial relationship between the digital surface model (DSM) and digital elevation model (DEM) could be clearly presented by overlapping the above six DSM cross-sections and DEM cross-sections.

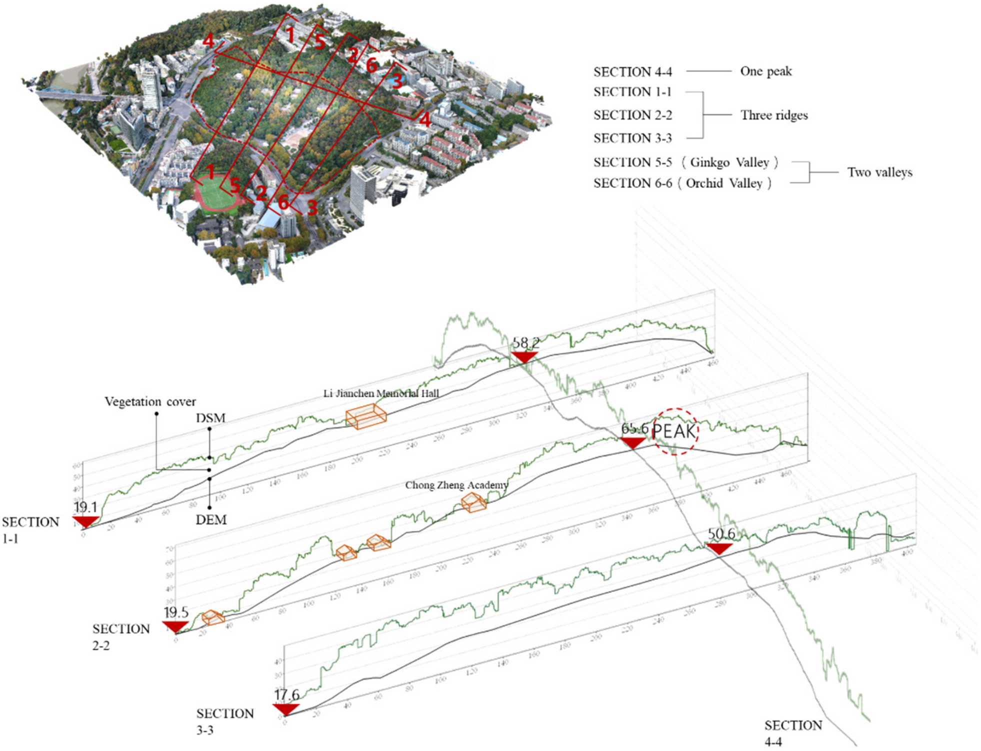

Fig. 7: Six typical sections of 3D real-scene model

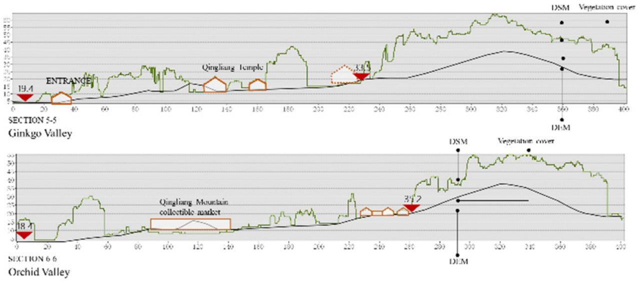

Fig. 7 (continued)

As shown in the cross sections, DEM laid a foundation for the basic spatial form, while plants, buildings and other ground objects shaped the spatial pattern and determined the spatial form perceptible externally.

According to the relationship between the six spatial profiles, the present topography of the level ground on the north side of the mountain was the highest, with an elevation of about 65.6m, which was the commanding height of the entire region. The highland vegetation on the north side of the mountain was high in canopy density. The vertical form of vegetation weakened the form of the mountain, the vertical change of the ridge morphology was relatively weak, and the ridge was not properly highlighted. The elevations of the three ridges from west to east were 49.7 m, 54.2 m and 46.8 m, respectively. Central ridge was the highest, where Chong Zheng Academy was located, as the spatial center of the southern section in Qingliang Mountain. The current vegetation coverage on the three ridges was high, with relatively few buildings constructed and fixed spatial morphology. In addition, the topography of Ginkgo Valley on the west side of the site was low in the north and high in the south. The terrain rose gently from south to north with the elevation distribution between 19.4 m to 33.5 m. Due to the influence of the current planting and buildings, the overall space was relatively closed with weak spatial continuity. The Orchid Valley on the east side of the site had the elevation distribution between 18.4 m to 35.2 m from south to north. There was a Qingliang Mountain collectible market on the south side of the valley, which had a relatively large architectural volume thus blocking the valley.

Therefore, in a later space renovation, it is suggested to maintain the spatial morphology of the ridge in Qingliang Mountain to reduce the disturbance to the existing vegetation. Forest form improvement can be performed at the mountain peak to optimize the ridge skyline morphology. The Orchid Valley on the east side of the site is an area of intensive activity in Qingliang Mountain area. Current external spatial morphology is complex, with excessively large building volumes blocking spatial continuity. This issue should be the focus of upgrading and renovating the site in the future.

5 Conclusion and Outlook

Through spatial modelling of landscape sites using a combination of UAV oblique photography technology and 3D laser scanning technology, 3D information and image information of the landscape space can be rapidly acquired in large scale. The model generated can present the 3D spatial layout of the landscape environment truthfully and intuitively, with comprehensive elements, clear texture, rich details, measurability, analyzability and other features. By using 3D laser scanning technology, the integrity and efficiency of large-scale spatial modelling can be achieved. Moreover, the assistance of 3D laser scanning technology has ensured the refinement of the details of local key sections. The technology is applicable to research sites with complex topographical conditions and various types of ground objects. Through 3D real-scene modelling, the quality of planning and design can be improved, which has provided a new technical route for the investigation and modelling of the landscape environment, to achieve rapid and precise spatial representation. The research results will serve as a foundation for further spatial investigations and provide the basis for later upgrades, renovations, optimizations and design interventions. There are still some shortcomings in this study and the accuracy of the model needs to be verified. In the future, we will conduct further sight analysis, wind speed simulation, light analysis, etc. to generate an in-depth understanding of a landscape using 3D real-scene model.

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