The Application of UAV-Based Oblique Photography in Urban Surveying and Mapping

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Abstract. UAV-Based Oblique Photography, by capturing high-resolution images from multiple angles and integrating computer vision and photogrammetry algorithms, provides an efficient and high-precision 3D modeling solution for urban mapping. Technology utilizes a UAV platform equipped with multiple cameras to synchronously acquire vertical and tilted images, and combines key technologies such as aerial Triangulation, multi-view stereo, triangulated irregular network and texture mapping, which significantly improves the realism and detail expression of the 3D model. Currently, technology has been successfully applied to large-scale topographic mapping, bridge inspection, and other fields, overcoming the limitations of traditional aerial photography and manual surveying. In the future, with the integration of deep learning technology, it will further optimize the model accuracy and automation level and promote its in-depth development in the fields of smart city and digital twin, such as the application of SurfaceNet and Generative Adversarial Network (GAN) framework. UAV-based oblique photography, with its advantages of low cost and high flexibility, is gradually becoming a core tool for modern urban mapping.

Keywords: Oblique Photography; UAV; Surveying.

1. Introduction

With the acceleration of urbanization, high-precision and high-efficiency geographic information data acquisition has become an important demand for modern urban mapping. Traditional vertical photography can only collect information from a single angle, which has obvious limitations. In recent years, the rapid development of UAV-based oblique photography provides a new solution for urban mapping. By shooting high-resolution images from multiple angles and combining computer vision and photogrammetric algorithms, this technology can quickly construct high-precision 3D real-world models, which significantly improves the mapping efficiency and data richness.

In recent years, with the maturity of drones and data processing software, many practical applications of this technology have appeared at home and abroad. In China, researchers use tilt photography technology to quickly establish the 3D real model of dangerous mountainous areas, so as to provide technical support for the identification and decision-making of geologic disasters [1]; researchers also monitor and measure the mining conditions of open-pit mines through tilt photography technology, accurately measuring the amount of ore mined and predicting the conditions of the future mining area after mining [2]. In Europe and the United States, HereMap released high-resolution tilt photography 3D city models of Berlin, Milan, Madrid, Los Angeles, and other cities around the world [3]; researchers used drone tilt photogrammetry technology in the generation of HBIM models of monuments in Spain, thus avoiding the irreversible damage of traditional terrestrial 3D laser scanning on monuments [4].

This paper discusses the application of UAV-based oblique photography in urban mapping, analyzing its technical principles, typical cases, and development trends. This paper firstly introduces the main basic principles and key technologies of UAV-based oblique photography, then introduces the practice of this technology in the field of topographic map surveying and mapping, bridge safety inspection, and finally introduces the future direction of technical development of this technology. Through the combination of theory and examples, it aims to provide technical reference for urban mapping workers and promote the in-depth application of this technology in the fields of smart cities and digital twins.

2. UAV-Based Oblique Photography

2.1. Fundamentals of UAV-Based Oblique Photography

UAV-based oblique photography is a technology for high-precision 3D modeling of ground targets using UAVs equipped with multiple high-resolution cameras. The number of cameras used for modeling with UAV-based oblique photography is mostly five, with one for vertical shooting and four for oblique shooting. During the shooting process, real-time position and status information are also obtained through sensors. In this way, the technology can obtain a highly realistic 3D city model. It greatly reduces the cost of obtaining a 3D model of the city.

The use of UAV-based oblique photography significantly improves the quality of the obtained 3D models. The traditional ways of acquiring remote sensing images are satellite photogrammetry, aerial photogrammetry and other ways [5]. These methods cannot obtain the side information of the ground target, and there will be problems such as elevation misalignment and unclear details. In contrast, tilt photography has a wider shooting range and has the ability to capture side information of ground targets. Therefore, the use of tilt photography technology can provide the possibility of providing low-cost, high-precision 3D models of cities.

2.2. Key Technologies of UAV-Based Oblique Photography

2.1.1 Aerial Triangulation

Oblique photography aerial triangulation mainly adopts POS aerial triangulation, and the steps include connection point extraction and shot-beam method area network leveling, and then the idea of extracting the connection point of tilted image is to take the outer orientation elements of the image provided by the POS system as the initial value, and then utilize scale and affine invariant feature algorithms to carry out multi-target feature matching, view the image, and get the connection point between the images. The shot-beam method area net leveling is the mainstream method of aerial triangulation, the algorithm is theoretically rigorous and encrypted with high accuracy, which is also suitable for aerial triangulation of multi-viewing point images.

This technology makes it possible to ensure both high accuracy and robustness of the output results when processing images in complex environments. In addition, this technology greatly improves the efficiency of image processing, allowing photogrammetry to be used in more fields, such as farmland surveying and forest mapping [6].

2.2.2 Multi-View Stereo

Multi-View Stereo is based on the principle of Photo-Consistency, under the premise of knowing the precise camera parameters, using the constraints of Epipolar Geometry to simplify the two-dimensional matching problem into a one-dimensional search along the polar line, so as to efficiently obtain a high density of homonymous points and read their three-dimensional coordinate information, and finally complete the generation of a three-dimensional dense point cloud [7].

The resulting point cloud has the characteristics of high detail and high precision, and will be used for the subsequent generation of DSM. This technology is widely used in many fields such as cultural heritage digitization, 3D mapping, film and television special effects, and architectural mapping due to its low cost and ability to handle large amounts of data.

2.2.3 Triangulated Irregular Network

Due to the limited range and pixels of cameras carried by UAV platforms, UAVs need to take a large number of photographs of the target's deployment range in order to obtain complete coverage. This makes the process of quickly and accurately stitching the large number of photos taken by the UAV into a seamless image very important. TIN (Triangulated Irregular Network) is a model that approximates the topography of a terrain by triangulating rigorous connections with precise 3D coordinates obtained through Multi-View Stereo. The key role of this technology in this process is that it provides the necessary elevation information in the form of a triangular mesh, which provides the topographic basis for subsequent image mapping and seam line generation.

During the analysis and processing, the algorithm will determine the geometric relationship between the generated triangular mesh model and the image intersection points and image boundaries, and will be able to make reasonable adjustments and adaptations according to the characteristics of the terrain type characterized by the generated model. For example, the grid structure of the 3D model generated by this method can effectively express the undulation trend of the ground surface, so it can better deal with natural terrain changes such as rivers, lakes, hills, etc., as well as elevation changes brought about by manmade buildings such as high-rise buildings, highways, bridges, etc., which can effectively reduce the seam misalignment problems that often appear in image stitching methods based on the planar assumption in subsequent image mapping phases, and this significantly improves the accuracy of results and realism[8].

2.2.4 Texture Mapping

Texture mapping is a computer graphics technology that fuses and maps texture information read from multiple 2D images onto the surface of a 3D model. The technology is able to automatically extract colors, patterns, textures and material attributes from images taken from different viewpoints and accurately fit them to the corresponding areas of the 3D model. The core principle is to establish the projection correspondence between the image pixels and the points on the surface of the 3D model through the relationship between camera parameters and spatial geometry, and to realize the high-precision mapping from 2D texture to 3D model with the help of coordinate system transformation.

This process not only enhances the visual realism of the model, but also significantly improves the detail expression. Texture mapping can effectively deal with complex surface structures, and is applicable to a variety of fields such as digital cultural heritage preservation, virtual reality, video games, and architectural visualization. The technologyis able to integrate information from multiple perspectives, reduce distortions and seams, and produce a more natural, consistent and highly realistic 3D model appearance.

3. Example of the Application of UAV-Based Oblique Photography

With the continuous development of UAV technology, the UAV platform is characterized by flexibility, low cost, wide shooting range and slow flight speed, which makes the UAV-based oblique photography have a strong ability to adapt to the environment. At the same time, the oblique photography technology can truly respond to the real texture and positioning information of the ground target.

3.1. Large-ratio 3D digital topographic mapping based on UAV-Based Oblique Photography

Large-scale topographic maps usually refer to topographic maps with a scale between 1:500 and 1:100,000, which are characterized by high positioning accuracy and rich and detailed feature and elevation information, and have become an indispensable spatial data base for modern municipal planning, infrastructure construction, land management and fine urban governance.

In the past, the production of large-scale topographic maps mainly relied on aerial photogrammetry and GPS-RTK technology, however, the former has limitations in the cycle of data acquisition and the adaptability to complex urban environments, and the latter is more accurate but less efficient and expensive, which makes it difficult to efficiently and economically satisfy the dual needs of large-scale mapping for both high-resolution and high-precision.

In recent years, the emergence of UAV-Based Oblique Photography has significantly improved the situation. With its advantages of flexible operation and lower cost, this technology can realize multi-angle and high-overlap image acquisition in urban areas, effectively obtaining fine texture and geometric information of complex features such as building facades, roads and bridges. Meanwhile, with the help of advanced automatic processing software, high-precision live 3D model and DSM can be quickly generated, and further output topographic map products that meet the large-scale standards [9]. Therefore, UAV-Based Oblique Photography not only dramatically improves the mapping efficiency and data detail expression, but also reduces the labor and time costs of traditional methods, and is gradually becoming a disruptive technology in the production of large-scale 3D digital topographic maps.

3.2. Bridge Inspection Based on UAV-Based Oblique Photography

Deformation measurement of bridges is one of the key indicators for assessing the health status and safety performance of bridge structures. Traditional measurement methods usually rely on equipment such as total stations, level meters and displacement sensors, which need to be operated manually by technicians on site. This method is not only cumbersome and has a long measurement cycle, but also has limited data coverage, which makes it difficult to comprehensively capture the dynamic response and local deformation of bridges in complex environments, and at the same time, there is a certain risk of manual error and high time and economic costs.

In contrast, UAV-based oblique photography can quickly obtain high-precision 3D point clouds and real-time models of the bridge surface and structure through multi-angle and high-overlap image acquisition. With the help of this technology, high-resolution modeling of the overall and detailed structure of the bridge can be realized, and all-around 3D data, including piers, girders, bridge decks and other parts can be obtained, so as to accurately analyze various deformation characteristics such as deformation, displacement, cracks, and settlement of the bridge [10]. This technology not only greatly improves the efficiency and completeness of data acquisition, but also can complete a wide range of monitoring with less manual intervention, which significantly saves time and resource investment, and provides strong technical support for the long-term health monitoring and intelligent management of bridges.

3.3. Modeling Urban Trees Based on UAV-based Oblique Photography

As a common landscape element in the urban environment, the modeling quality of trees largely determines the realism and visual effect of the entire urban 3D model. However, due to the complex morphology of trees, the detailed texture of branches and leaves, and the highly random and irregular spatial distribution of trees, it is often difficult for traditional modeling methods to balance the requirements of high realism and low time-consumption. Although manual modeling can achieve high visual quality, it is time-consuming and costly; while automated generation methods often have obvious deficiencies in detail performance, making it difficult to meet the demand for high-quality visualization.

The fundamental reason for this dilemma is that the geometric structure and surface texture of trees are highly complex and visually confusing, especially the spatial distribution of leaves, light response, and the transition of details between different layers, which puts extreme demands on the modeling algorithms. To address this challenge, researchers proposed a modeling optimization method based on control parameter analysis (CPA) and combined it with an automatic level of detail (LOD) control strategy to generate a high-quality tree model with multiple levels of detail in about ten minutes [11].

This advancement provides a feasible technical path for efficient and high-quality modeling of vegetation in large-scale urban scenarios, which is especially suitable for application areas such as digital twins, smart cities, game development, and virtual reality, which have high requirements for model quality and generation efficiency.

4. Future Directions of UAV-based Oblique Photography

Today, 3D modeling using UAV-based oblique photography still has multiple limitations. This is specifically manifested in the lack of model accuracy, local geometric deficiencies, texture brightness distortion, and limited ability to reproduce details in complex scenes. Especially in areas with dense vegetation, severe building obstructions, or drastic changes in lighting conditions, the models often suffer from holes, distortions, or noise problems. In addition, data acquisition is greatly affected by flight altitude, camera parameters and weather conditions, and traditional beam method leveling and multi-view matching algorithms often perform poorly when dealing with highly heterogeneous data, resulting in low model reliability and generalizability.

In the face of these challenges, the introduction of deep learning technology has brought new development opportunities to the field. The future development trend is mainly reflected in the following aspects: firstly, SurfaceNet, an end-to-end neural network-based architecture, can learn the mapping relationship between surface geometry and optical features directly from the image, which significantly improves the accuracy and completeness of 3D reconstruction [12]. Secondly, deep learning models such as Generative Adversarial Network (GAN) can effectively compensate for the quality defects of the original image by augmenting and optimizing the training data, and improve the robustness of the model under complex lighting conditions such as shadows and reflections [1]. These technologies will promote the development of UAV-based oblique photography modeling in the direction of higher precision, stronger adaptive and lower cost, and provide more reliable technical support for the fields of smart city, cultural heritage protection, and geologic disaster assessment.

5. Conclusion

This paper summarizes the basic principles, application examples and development trends of UAV inclined photogrammetry technology. The technology is used to obtain a real and accurate 3D model by computationally fusing the images captured by the UAV platform. The main key technologies are aerial triangulation, multi-view stereo, texture mapping and TIN generation. Nowadays, due to its advantages of low cost, flexibility, and high accuracy, this technology has been realized in large-scale topographic mapping and bridge inspection. In the future, deep learning will continue to be integrated with this technology to achieve faster computation and higher accuracy. This technology has become an important technology in the construction of smart cities and digital twins, and has become an important part of urban planning, surveying, and maintenance. With the continuous integration of this technology and deep learning technology, the manual adjustment work in the generation process of 3D models will be reduced and the overall model accuracy and realism will be improved.

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