Application of UAV-based 3D modeling and visualization technology in urban planning

Huizhe Sang
Beijing Royal School, Beijing, China
18835669876@163.com

Abstract. With the acceleration of urbanization, urban planning is increasingly demanding for data accuracy and visualization capability. UAV-based 3D modeling and visualization technology provides an efficient and accurate solution for urban planning. UAVs collect geographic and architectural information by carrying a variety of sensors to generate high-resolution images and point cloud data, which are further used to construct accurate 3D city models and enhance the realism of the models through texture mapping and optimization. Based on these models, 3D visualization technology provides urban planners with an intuitive means of spatial analysis and dynamic monitoring, and enhances the efficiency of planning and design, environmental monitoring, and construction management. This paper explores examples of the application of UAV technology in urban planning, demonstrating its great potential for improving planning accuracy, management efficiency, and decision support.

Keywords: drone technology, 3D modeling, visualization technology, urban planning, data acquisition, point cloud generation, dynamic monitoring, virtual reality, augmented reality.

1. Introduction

With the accelerating global urbanization, the challenges of urban planning are becoming more and more complex, and the traditional planning methods can hardly meet the growing city scale and diversified needs[1]. Modern urban planning requires not only high-precision geographic data, but also visualization tools that can effectively display and analyze multi-dimensional information[2]. In this context, UAV-based 3D modeling and visualization technology has emerged[3]. By collecting real-world data from UAVs and using computer technology to perform 3D modeling, this technology shows great potential in the fields of urban planning, environmental monitoring, disaster risk assessment, and infrastructure planning[4].

UAV technology is capable of acquiring large-scale high-resolution data quickly and flexibly without being restricted by the complexity of terrain, and is particularly suitable for the acquisition of key information such as buildings, transportation and green space layout in urban environments.UAVs are very efficient in data acquisition, can quickly cover large areas without being restricted by terrain, and have greatly improved the speed of data acquisition[5]. Compared with traditional ground mapping and aerial photography, UAVs are able to accomplish data acquisition tasks at a lower cost and with greater flexibility[6]. At the same time, 3D modeling technology is able to generate accurate 3D city models with the help of point cloud data and images collected by drones, and further enhance the realism and detail performance of the models through texture mapping and other technologies. Point Cloud Density:

$$D = \frac{N}{V} \tag{1}$$

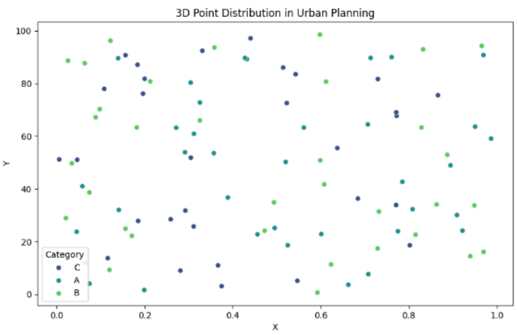
The application of 3D visualization technology provides urban planners with intuitive tools to analyze urban spatial layout more comprehensively, assess the feasibility of planning schemes and make dynamic adjustments[7]. Especially with the combination of Virtual Reality (VR) and Augmented Reality (AR) technologies, planners are able to evaluate and optimize the design in an immersive environment, which greatly improves the scientific and operability of planning[8]. The construction of real-life 3D models of cities has become a hotspot of current research and application, and large and medium-sized cities have carried out urban 3D model construction projects one after another[9]. The application of UAV-based 3D modeling and visualization technology in urban planning has a broad prospect, which can effectively improve planning accuracy, optimize resource allocation, and provide dynamic monitoring means for urban management[10]. In this paper, we will discuss in depth the specific application of this technology in urban planning, and demonstrate its value and potential in actual scenarios through case studies[11].

2. Application of drone technology in data acquisition

UAV technology has become an indispensable data collection tool in urban planning because of its flexibility, mobility and efficiency[12]. Compared to traditional ground-based mapping and satellite remote sensing, drones are able to fly flexibly in complex urban environments and quickly acquire high-resolution data over large areas. By carrying a variety of sensors, such as optical cameras, LIDAR and thermal imaging equipment, drones can comprehensively collect geographic information, building heights, terrain features and other data, providing accurate and detailed basic information for urban planning. This fast and efficient data collection method greatly shortens the cycle of information acquisition and is particularly suitable for dynamically changing urban environments. 3D Model Surface Area:

$$A = \sum_{i=1}^{n} A_i \tag{2}$$

In different urban planning application scenarios, fixed-wing UAVs have the advantages of long range and large coverage, and are suitable for large-area terrain mapping, such as overall urban planning and transportation route planning. Multi-rotor UAVs, on the other hand, have strong maneuverability and hovering ability, and are suitable for capturing architectural details in complex terrains, especially in city center areas with dense high-rise buildings. In addition, the size of the UAV, flight altitude and the type of sensor it carries also affect the effectiveness of data collection, and planners need to make choices based on specific needs to ensure the quality and accuracy of the collected data. Optical cameras can capture high-resolution 2D images, which can be used to generate 3D models with rich surface details; LiDAR can acquire high-precision 3D point cloud data, which is particularly suitable for the measurement of complex landforms such as building heights and terrain undulations; and infrared sensors can be used to monitor thermal energy distribution, which is suitable for environmental monitoring and energy management. Through the combination of different sensors, the UAV is able to collect multiple types of data simultaneously in a single flight, providing a full range of information support for urban planning， showed in Figure 1 :



Figurue 1 3D Point Distribution in Urban Planning

Traditional data collection methods are often unable to update detailed information about urban areas in a timely manner due to terrain or time costs, while drones are able to flexibly cope with complex environments and obtain newer and more detailed geographic information. To ensure the accuracy of the data, post-processing, such as image stitching, point cloud data filtering and correction, is usually required after data acquisition to remove noise and improve data consistency. The accuracy of data processing has a direct impact on the effectiveness of subsequent 3D modeling, and is therefore an important part of UAV applications. UAVs have significant efficiency advantages over traditional methods. The degree of image overlap is very important for modeling accuracy, the higher the image overlap, the more common points between the images, the higher the modeling accuracy, but we cannot just pursue the measurement accuracy, the higher the overlap, the larger the data volume of the film, and the workload for data storage as well as later data processing will also increase. A single flight can cover a large area and complete the acquisition of high-resolution data in a short period of time, enabling planners to quickly obtain the required basic information. This advantage is especially prominent in time-critical projects such as emergency planning and post-disaster reconstruction. In addition, through real-time transmission technology, some UAVs can transmit the collected data directly to the ground station for real-time analysis and processing. This real-time nature provides great convenience for planning adjustments and monitoring in dynamic urban environments.

3. 3D modeling techniques based on drone data

Based on the data collected by drones, 3D modeling technology is able to generate accurate three-dimensional city models to help urban planners carry out more detailed design and analysis. The process mainly includes data processing and point cloud generation, model construction and optimization, as well as texture mapping and model realism enhancement, which together ensure the accuracy and visualization of the 3D model to meet the various needs in urban planning.

4. Data processing and point cloud generation

The data collected by UAVs usually consists of a large number of high-resolution images, LiDAR (laser radar) scan data, or information collected by other sensors. These data are usually raw, unprocessed data that contain a lot of redundant information and noise, and thus require data preprocessing to improve their quality. UAV tilt photogrammetry acquires images of the survey area from five lenses in different directions, and the images cannot avoid the existence of occlusion and scaling, and the triangulation of the vertical survey cannot solve such problems, so the image processing is carried out by means of multiview image union. At this stage, image stitching, alignment and denoising processes are particularly important to ensure that the subsequently generated point cloud data have high accuracy. Volume Calculation:

$$V = \int_D dV \tag{3}$$

During flight, drones usually capture multiple images covering different urban areas. In order to generate a complete 3D model, these images must be accurately stitched together. Multiview image joint leveling is an important step in data processing. For tilt photogrammetry, the multiview image includes both vertical and tilted image types, so the image matching algorithm chosen for joint leveling needs to ignore the image distortion. Through the image matching algorithm and feature point recognition technology, seamless matching between multiple images can be realized, which in turn generates a complete image covering the entire planning area. In this process, the splicing accuracy needs to be ensured to avoid overlapping or offset resulting in model data errors,showed in Figure 2 :

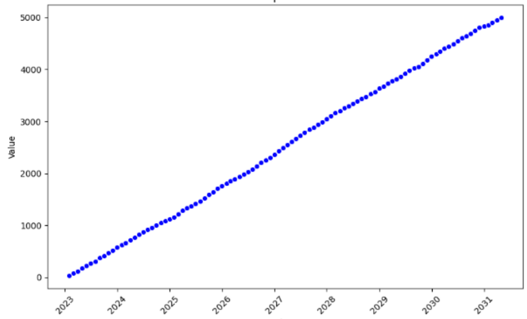


Figure 2 Cumulative Development Value Over Time

After stitching is complete, a point cloud is a collection of three-dimensional data consisting of a large number of points, each of which represents a certain coordinate position on the surface of an object. By converting the spliced 2D images or LIDAR data into 3D point clouds, stereoscopic data with a high degree of information can be obtained. These point cloud data provide the basis for subsequent 3D model construction, and their accuracy directly determines the level of detail of the model. When the point cloud is generated, data compression and optimization are also required to reduce redundant points and improve computational efficiency.

According to the needs of mapping tasks to choose the appropriate sensors, commonly used optical cameras, LIDAR, thermal infrared cameras and so on. Different sensors have different measurement characteristics and applicable scenarios, such as optical cameras can be used for feature identification and three-dimensional reconstruction, LIDAR can be used for digital elevation modeling, and thermal infrared cameras can be used for the study of urban heat island effect. The UAV flight may be affected by environmental factors such as wind speed and light, and the collected data may be noisy or inaccurate. By applying the filtering algorithm, unnecessary noise points and error points can be removed to ensure the clarity and accuracy of the point cloud data. Through the correction algorithm, the geometry of the point cloud is further adjusted to make it more consistent with the actual urban terrain and building structures. Texture Mapping Coordinates:

$$(u, v) = \left(\frac{x - x_{\min}}{x_{\max} - x_{\min}}, \frac{y - y_{\min}}{y_{\max} - y_{\min}}\right) \tag{4}$$

5. Model Construction and Optimization

Model construction and optimization is the core part of the UAV 3D modeling process, which aims to transform the processed point cloud data into a high-quality 3D model. Texture matching is a crucial step in the establishment of a real-world 3D model. After the established white model meets the requirements for each limit difference, the 3D model is reconstructed in the software, and the point cloud data can be transformed into a mesh model through 3D reconstruction algorithms, such as structured light or stereo vision techniques. This process involves extracting the boundaries of the object from the point cloud and generating a triangular mesh to form the 3D surface. The accuracy and level of detail of this mesh depends on the quality of the point cloud, so it is crucial to ensure that the point cloud is of high quality at this stage in order to obtain a smooth and realistic 3D surface,showed in Figure 3 :

Figure 3 Income Variation Across Different Urban Areas

After the mesh model is constructed, the next step is to optimize the model to improve its performance and visualization. Model optimization typically includes reducing the number of polygons, smoothing surfaces, and fixing defects in the mesh. The reduction in the number of polygons helps to improve the rendering speed of the model so that it can be smoothly displayed on various devices. In addition, smoothing removes unnecessary sharp edges, giving the model a more natural appearance. By streamlining and optimizing the details of the model, planners can improve the efficiency of subsequent analyses while ensuring visualization.

After completing the model construction and optimization, various visualization software and tools are used to set the material, lighting and shadow of the model to further enhance the realism and detail performance of the model. Through texture mapping technology, applying high-resolution image information to the model surface can make the model more visually impactful and help planners better understand and analyze the urban space. A good visualization effect can improve the acceptance and influence of the model in public display, and promote the transparency of urban planning and public participation. Lighting Model (Phong Reflection Model):

$$I = k_a I_a + k_d (I_d \cdot N) + k_s (I_s \cdot R)^{\alpha} \quad (5)$$

The process of model construction and optimization is not a one-time completion, but a dynamic and iterative process. As the urban environment changes, the model needs to be updated regularly to reflect the latest geographic information and building status. This updating process can be realized through UAV re-flights and data collection, thus ensuring the long-term validity and applicability of the model. In addition, through continuous optimization and updating, urban planners are able to obtain the latest information in a timely manner, make scientific and reasonable planning decisions, and enhance the intelligent level of urban development and management.

6. Texture mapping and realism enhancement

Texture Mapping and Realism Enhancement The construction of smart cities requires a large amount of spatial and geographic information, so mapping engineering plays an important role in the construction of smart cities. Smart city construction requires a large amount of geographic information, including all kinds of spatial data, three-dimensional models, topography and geomorphology, underground pipe networks, building heights, road networks and so on. And the purpose of mapping engineering is to obtain all kinds of information about the earth's surface through a series of surveying methods. Texture mapping and realism enhancement are the key steps in UAV 3D modeling technology, through which the visual quality and detail performance of the model can be greatly improved. After completing the basic 3D model construction, applying high-resolution images as textures to the model surface can give the model richer visual information and make it closer to the real world in terms of color and details. This process typically involves matching the captured image to the model's geometric data and accurately mapping the image to the model surface via texture coordinates to ensure that every surface detail is represented,showed in Figure 4 :

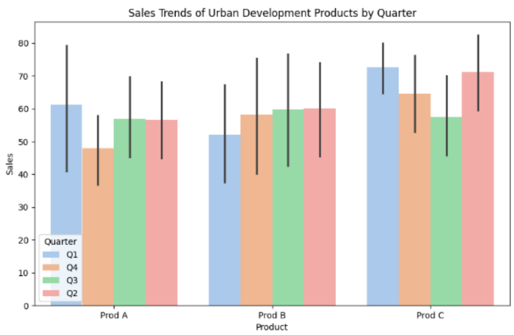


Figure 4 Sales Trends of Urban Development Products by Quarter

When performing texture mapping, a rational UV unfolding process involves unfolding the surface of a 3D model to generate correspondences on a 2D plane in order to accurately map the image information onto the model. By optimizing the UV coordinates, texture distortions and seams can be minimized, thus enhancing the overall visual coherence. In addition, the appropriate texture resolution is crucial. Too low a resolution may result in a blurred image, while too high a resolution may affect the rendering performance of the model, so a balance between detail and performance needs to be found. Urban Growth Model:

$$G(t) = G_0 e^{rt} \quad (6)$$

In addition to texture mapping, realism enhancement techniques can make a model more visually realistic by adding lighting, shadows, reflections, and other effects. Technologies such as global illumination modeling and Physical Base Rendering (PBR) can simulate the propagation of real light in the environment to further enhance the three-dimensional and spatial sense of the model. Especially in complex urban environments, reasonable lighting and shadow processing can greatly enhance the realism of the model and make the audience feel immersed when observing.

In order to further enhance the realism of the model, the stage of post-rendering and effect adjustment, the planners use professional visualization software to make rendering settings, including the adjustment of parameters such as ambient light, reflectivity, and material properties. At the same time, post-processing techniques, such as depth of field and color correction, can be used to optimize the visual effects of the final output. These enhancement techniques not only improve the viewability of the model, but also provide urban planners with more attractive visualization results when displaying and publicizing, which enhances the public's motivation and interest in participating in urban planning.

7. Application of 3D Visualization Technology in Urban Planning

3D visualization technology is increasingly used in urban planning. By combining Geographic Information Systems (GIS) with 3D models, planners, designers and decision makers are able to visualize city layout, traffic flow, green space distribution and other information in a virtual environment. Such visualization makes complex urban planning data easy to understand and helps stakeholders to better identify problems and opportunities in urban development. In addition, 3D visualization can intuitively show the impact of the planning scheme, which helps public participation and feedback, and enhances the transparency and public acceptance of planning.

In the urban design stage, 3D visualization technology enables planners to intuitively observe the strengths and weaknesses of different schemes, including architectural form, space utilization, and greening configuration, by constructing different design models. Sunlight analysis is an essential element. For new subdivisions, the most direct sunlight analysis is the sunlight shading analysis based on the actual height of the building. In the urban reality 3D model can be based on the planning and construction of tall buildings for 1:1 replication, through the adjustment of light time and direction, the study of each building's light height and time changes. This visualization makes multi-program comparison more efficient, and planners can make decisions in a shorter time and provide data support for the selection of the final program. At the same time, with the help of virtual reality (VR) and augmented reality (AR) and other technologies, planners and designers can "roam" in the virtual environment, more intuitively feel the future of the city's spatial experience, and this immersive experience will help to improve the reasonableness of the design and scientific,showed in Figure 5 :

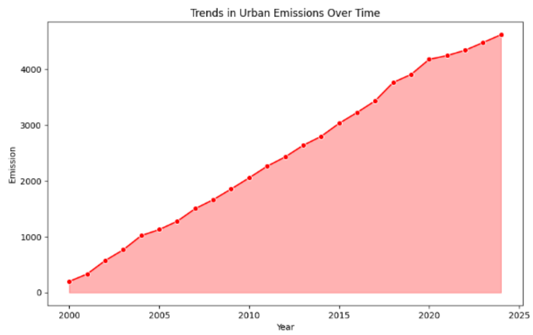


Figure 5 Trends in Urban Emissions Over Time

For important landscapes and attractions, the visual field analysis is extremely important, and the surrounding buildings are too high to block the line of sight, affecting the value of urban tourism. Therefore, the visual field needs to be fully considered in the process of urban planning. Through the 3D model of urban reality, the visual range can be studied according to the given observation point, observing whether the important targets are within the visual range, and the angle and distance can be adjusted according to the actual need to analyze the buildings within the visual range. In the process of project implementation, 3D visualization technology allows planners to monitor the execution of the project in real time and identify possible deviations and problems by comparing the actual construction progress with the 3D model. This dynamic visualization makes project management more efficient and enables timely adjustments to be made to ensure that the project is carried out in accordance with the intended goals. In addition, combined with drone technology, real-time data collection and updating makes the visualization content reflect the latest developments in urban construction in a timely manner, which enhances the intelligent level of urban management.

3D Visualization Technology for Post-Evaluation and Feedback in Urban Planning By evaluating the 3D model of an implemented project, planners can analyze the impact of the project on the surrounding environment, identify potential problems, and provide references for subsequent urban development. This process not only helps to improve the science of future planning, but also provides a basis for policy formulation. By establishing a feedback mechanism for urban planning, 3D visualization technology helps city managers to continuously optimize planning solutions and achieve the goal of sustainable development.

8. Conclusion

In the field of urban planning, UAV-based 3D modeling and visualization technology shows great potential and application value. Through efficient data acquisition, accurate point cloud generation, comprehensive model construction and optimization, as well as detailed texture mapping and realism enhancement, planners gain an in-depth understanding of all aspects of urban space in an intuitive 3D environment. It not only improves the science and rationality of planning, but also effectively promotes public participation and feedback, and enhances the transparency of urban planning.

With the acceleration of urbanization and the increasing complexity of challenges faced by cities, traditional planning methods are no longer able to meet the actual needs. the introduction of 3D visualization technology provides an innovative solution for urban planning. It not only facilitates the comparison and optimization of solutions in the design phase, but also provides strong support to decision makers in the implementation and evaluation phases. By monitoring project progress and analyzing implementation effects in real time, city managers are better able to respond to changes and challenges and ensure that the goal of sustainable urban development is achieved.

With the continuous advancement of technology, the combination of UAV-based 3D modeling and visualization technologies, especially emerging technologies such as virtual reality (VR) and augmented reality (AR), will make the visualization of urban planning more realistic and vivid. This will provide a richer interactive experience for planners and the public, and promote in-depth understanding and communication of urban space. UAV-based 3D modeling and visualization technology is not only a tool for urban planning, but also an important way to realize smart cities. By continuously exploring and applying this technology, urban planners will be able to better grasp the pulse of urban development and create a better vision for the future of cities.

References

[1] Mahni?-Kalamiza S , Kotnik T , Miklav?I? D .Educational application for visualization and analysis of electric field strength in multiple electrode electroporation[J].Bmc Medical Education, 2012, 12(1):102-102.DOI:10.1186/1472-6920-12-102.

[2] Ikuko F , Evans D L , Moorhead R J ,et al.Stand Assessment through Lidar-Based Forest Visualization Using Immersive Virtual Environment Technology[J].Forest Science, 2008(1):1-7.DOI:10.1016/j.forpol.2007.11.004.

[3] Shin D .Visualization of 3D Objects in Scattering Medium Using Axially Distributed Sensing[J].Journal of Display Technology, 2012, 8(6):317-320.DOI:10.1109/JDT.2011.2176917.

[4] Teizer J , Cheng T , Fang Y .Location tracking and data visualization technology to advance construction ironworkers' education and training in safety and productivity[J].Automation in construction, 2013, 35(nov.):53-68.DOI:10.1016/j.autcon.2013.03.004.

[5] Apostolos P , Konstantinos T , Gerasimos P .Coastline Zones Identification and 3D Coastal Mapping Using UAV Spatial Data[J].ISPRS International Journal of Geo-Information, 2016, 5(6):75.DOI:10.3390/ijgi5060075.

[6] Zhang Y H , Tang L , Liu X J ,et al.(ASC-2013-0100) Modeling Dynamics of Leaf Color Based on RGB Value in Rice[J].Journal of Integrative Agriculture, 2013, 13(4):749-759.DOI:10.1016/S2095-3119(13)60391-3.

[7] Sviridov V V , Kotsyuk D V , Podorozhnyuk E V .Photogrammetric Counts of Pacific Salmon Using Consumer-Grade Unmanned Aerial Vehicles[J].Russian Journal of Marine Biology, 2022, 48(7):587-600.DOI:10.1134/S1063074022070136.

[8] Lin J , Wang Y , Fierro Z R .Low-Complexity Control for Vision-Based Landing of Quadrotor UAV on Unknown Moving Platform[J].IEEE transactions on industrial informatics, 2022, 18(8):5348-5358.

[9] Siliang C , Qingwu H , Shaohua W ,et al.A Virtual Restoration Approach for Ancient Plank Road Using Mechanical Analysis with Precision 3D Data of Heritage Site[J].Remote Sensing, 2016, 8(10):828.DOI:10.3390/rs8100828.

[10] Wang D , Lian B , Gao L B .A Cooperative UAV Swarm Localization Algorithm Based on Probabilistic Data Association for Visual Measurement[J].IEEE sensors journal, 2022, 22(20):19635-19644.

[11] Lipovsk P ,Katarína Draganová,Jozef Novotňák,et al.Indoor Mapping of Magnetic Fields Using UAV Equipped with Fluxgate Magnetometer[J].Sensors, 2021, 21(12):4191.DOI:10.3390/s21124191.

[12] Puppala A J , Congress S S C , Bheemasetti T V ,et al.Visualization of Civil Infrastructure Emphasizing Geomaterial Characterization and Performance[J].Journal of materials in civil engineering, 2018, 30(10):04018236.1-04018236.12.DOI:10.1061/(ASCE)MT.1943-5533.0002434