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Application of 3D Digital Modeling Technology in the Construction of Digital Cities

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Abstract

The concepts of "digital twins", "3D real scene", "metacosm" and others were the technical paths for building digital cities with the development of emerging surveying and mapping science and technology, which was to build a digital and virtualized city that matched the real physical world, to achieve a one-to-one correspondence between all elements of the physical world and the digital virtual world. And one of its basic geographic information data was a highly similar, virtual simulation of the 3D real scene. After exploring the traditional manual 3DsMax modeling, UAV low-altitude digital oblique photogrammetry modeling, airborne laser scanning modeling and other single modeling technologies, this paper discussed the 3D digital modeling technology used by the UAV airborne laser scanning point cloud and low-altitude digital oblique photogrammetry for complementary integration, constructing the 3D scene of the digital city. This paper expounded the technical route and production process of 3D digital modeling, in order to provide technical references for related projects.

Keywords

Airborne Laser Scanning Point Clouds, Low-Altitude Oblique Photogrammetry, Real Scenes, Digital City, Digital Twins

1. Introduction

In recent years, "digital twins", "3D real scene", and "metacosm" are with the development of emerging geomatics science and technology as one of the technical ways to build a digital city. In 2021, the Ministry of Natural Resources General Office issued the "3D Real Scene China construction technology outline (2021 edition)". Since then, the 3D Real Scene China is in more and more cities and surveying and mapping geographic information industry upstream and downstream enterprises in full swing [1]. "Digital twins" refers to the digital and virtualized mirror city built in the digital virtualized network space that matches the mapping of various environmental elements in the real physical world, mainly for urban governance and operation and maintenance. The underlying digital base is a highly similar, virtually simulated real-world 3D scene.

One of the current hot spots in the development and research of geographic information industry is to focus on improving the efficiency, area and sophistication of the production and construction of city-level, real-world 3D scenes [2]. Based on the aircraft equipped with a multi-lens sensor, low-altitude oblique photogrammetry to obtain digital images to build 3D Real Scene is imported from abroad in recent years in China widely used, and gradually replaced the traditional manual use of 3dsMax manual method for 3D Real Scene construction of new technologies, new processes and new methods. Its main operation process is on the same flight platform equipped with multi-lens visible light digital camera, Aerial images reflecting the reality of the ground are obtained from different angles of vertical photogrammetry and oblique photogrammetry at the same time and location, and then processed by using real-world 3D modeling software to form a real-world 3D scene [3].

Airborne laser scanning technology is a non-contact earth observation technology that actively emits multi-threaded laser signals after oblique photogrammetry, which is different from the acquisition of planar image data and is characterized by small influence, by thin clouds and mist and weather light, high penetration, ability to obtain 3D coordinates of the subject, high accuracy of raw data and short production operation cycle [4]. In this paper, we compare a variety of real-world digital 3D modeling methods, and try to explore the method of fusing two heterogeneous data obtained by on-board laser scanning point cloud and a digital image acquired by oblique photogrammetry to construct a real-world 3D scene. This paper expounds the technical route and production process of 3D digital modeling, in order to provide technical references for related engineering projects.

2. 3D Real Scene Modeling Method

The basic data for producing 3D scenes is generally metadata with accurate geographic location information. The production process is continuously upgraded and updated with the upgrading and transformation of the geographic information industry and the emergence of new technologies, new processes, and new methods. The 3D real scene modeling methods mainly include traditional 3dsMax manual modeling, semi-automatic human-computer interaction modeling based on oblique photogrammetry, and digital image fusion model based on point cloud and oblique photogrammetry acquisition based on on-board laser scanning [5] [6].

The first method is modeled manually using 3dsMax software, which mainly uses large-scale digital line graphic, low-altitude vertical photogrammetry to obtain images and on-site real-world building images. Manually construct white modes, picture retouching and texture mapping in 3ds Max. The second method is done by using low-altitude oblique photogrammetry to obtain images through human-computer interaction semi-automatic modeling software. The data source is mainly through the on-board multi-lens visible camera earth observation to obtain oblique photogrammetry images. In most cases, it is a vertical and multiple inclined angle of the surface image, combined with artificially laid ground image control points in the human-computer interaction semi-automatic modeling software for 3D modeling and modification.

The third method is a fusion model of the digital image obtained by the on-board laser scanning point cloud and oblique photogrammetry. This method is proposed because if only the image obtained by oblique photogrammetry is distorted. Deformed or pulled by the local details of the real scene through the semi-automatic modeling process of human-computer interaction, and on this basis. The point cloud data formed by the on-board laser scanning can reduce or eliminate the above phenomenon, and realize the fully automatic or human-computer interaction semi-automatic extraction of 3D structural model of the ground feature (mainly referring to buildings and structures). The image obtained by oblique photogrammetry automatically extracts the top and side textures of the figure. The position of individual buildings that are self-obscured or obscured by trees needs to be artificially modified with graphic image processing software and then mapped to the three-dimensional structural model of the figure. Through the complementary integration of the above two technologies, the structure of the real-life three-dimensional scene (model) is more accurate, the visualization effect is better, and the post-repair work is less. Table 1 compares the three different modeling methods from five aspects: basic data, process flow, production results, production cycle, and scene features.

3. Technical Route Design

The technical route design of digital image fusion modeling using on-board laser scanning point clouds and oblique photography can be divided into four stages: the pre-preparation stage, the data acquisition and pre-processing stage, the real 3D scene construction stage, and the quality inspection and acceptance stage.

1) The preliminary preparation stage includes surveying the site, collecting data in the measurement area, writing and reviewing technical design books, and preparing for field aerial photogrammetry. Writing and reviewing the technical design book is one of the important tasks in the early stage of the whole project, involving work plans, technical routes, operational requirements, technical standards and other aspects. The main work of the field aerial photogrammetry is to understand the basic situation of the measurement area in detail, to map the boundaries of the range, to obtain local weather forecasts and airspace applications and approvals, and to check and verify whether the airborne and ground equipment are normal.

Table 1. Comparison of 3D digital modeling techniques.

Items	3dsMax Traditional modeling	Oblique photogrammetry semi-automated human-computer interaction modeling	Onboard laser-scanned point clouds are modeled in conjunction with oblique photographic imagery
Basic data	Large-scale digital line graphics, vertical photogrammetry images, and partial textures of figures obtained by manual field re-shooting.	Photogrammetry images, flight control data, ground control points, etc.	Airborne laser point cloud, oblique photogrammetry image, flight control data, ground control point, etc.
Process flow	Manually determine the position of the figure in the 3dsMax with digital line graphics, manually generate white molds, process images, and fit textures.	Images of the top and sides of the figure are obtained through oblique photogrammetry, and only image modeling is used.	Multi-angle image fusion modeling of the top and side of the figure is obtained through on-board laser point cloud and oblique photogrammetry, and the point cloud generates structure and the image fits the texture.
Production results	Most of them are patch structure data, that is mesh surface models.	4D products can be generated, 3D real scene models.	4D products can be generated, 3D real scene models.
Production cycle	The cycle is long and inefficient, with less than one square kilometer per day.	Short cycle times, moderate efficiency, and human-machine interactive semi-automatic modeling.	The cycle time is long, the efficiency is high, the modeling is almost fully automated, and there is less manual intervention.
Scene features	Artificially constructed digital and virtualized 3D scenarios.	The real scene digitizes the three-dimensional scene. But it is easily deformed and distorted by the occlusion position and hidden position of itself or foreign objects.	In the 3D real scene, the figure structure generated by the laser point cloud is accurate, and the texture mapping of the oblique image is clear.
	The process is cumbersome, the operation is complex, the degree of automated modeling is low, the time and experience of manual investment are more.	The process is simple, the degree of automated modeling is fast and efficient, and the workload of manual editing data is reduced.	The process is simple and the difficulty of operation is moderate. Most in-house workflows can be automated, but areas with poor aesthetic results require manual intervention to repair.

2) The data acquisition and processing stage includes low-altitude airborne laser point cloud data processing and oblique photogrammetry image data processing. First, the key technology of airborne laser point cloud pre-processing is to identify point clouds that are classified into point clouds and non-ground point clouds that represent the ground through algorithms. Ground control points are the basis for generating digital elevation models, and non-ground points are used to generate building frame models. Second, the core of oblique photogrammetry image data processing is to extract the top and side textures of buildings in multi-angle aerial photogrammetry, and to generate texture maps of the building frame model by editing texture data (cropping and correcting colors). Third, the position corresponding to the deformation distortion and the focus blur of the unqualified texture is screened, and the secondary supplement

is required.

3) The 3D real scene construction stage mainly uses the digital elevation model. The building frame model and the modified texture generated in the second stage to complement and integrate the 3D modeling through the corresponding algorithm.

4) The 3D real scene quality inspection and acceptance stage is mainly carried out from the four aspects of position accuracy, model structure, model texture and scene effect [7]. If the data quality inspection elements are decomposed in detail, they can be further checked from the following six angles, namely: a) coordinate reference system (plane reference, elevation reference and projection); b) position accuracy (plane position accuracy, elevation accuracy); c) model quality (model structure quality, image texture quality, terrain and figure quality); d) logic (whether the output format is uniform); e) scene effect (whether the status quo is complete, whether the scale is coordinated, whether the scene is beautiful); and f) attachment quality (whether the documentation is complete, whether the metadata is correct and complete).

4. 3D Real Scene Modeling of the Production Process

4.1. Classify Airborne Laser Point Cloud Data

The point clouds obtained by on-board scans are the basic data for making digital elevation models and building frame models. Point cloud data is typically classified as ground and non-ground points [8] based on the location and elevation attributes of the feature terrain reflected by the point cloud. The former reflects the true undulating form of the surface of the real world, representing the bare surface or points that fit into the ground, such as the fields and roads. The latter are points that do not fall on the bare surface, such as the power pole towers, street lamps and buildings (structures). A schematic diagram of the onboard laser scanning point cloud classification process is shown in **Figure 1**.

4.2. Produce Digital Elevation Model

The production process of the digital elevation model mainly includes four steps: airborne laser point cloud classification, generation of digital orthophoto map (DOM), search for spatial location anomalies, and generation of irregular triangle networks, production DEM [9]. Usually, the first is to pre-processing the onboard laser point cloud and classify it to select the point representing the ground. Second, the image index is established by using the aerial trajectory, image time file, aerial camera (aerial camera) inspection parameters, fixed position positioning system (IMU) data, etc., to produce digital orthophoto maps. Third, based on the digital terrain model (DTM), refer to the digital orthophoto map to find the spatial location anomaly and manually correct the anomalous point area. Fourth, the processed point cloud generates an irregular triangle network and generates DEM by interpolation. A schematic of the digital elevation model production process is shown in **Figure 2**.

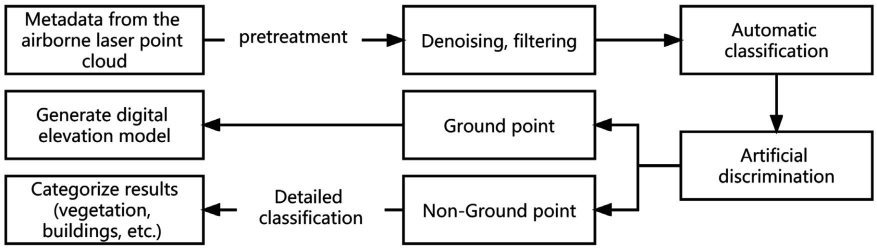

Figure 1. Schematic diagram of airborne laser point cloud classification process.

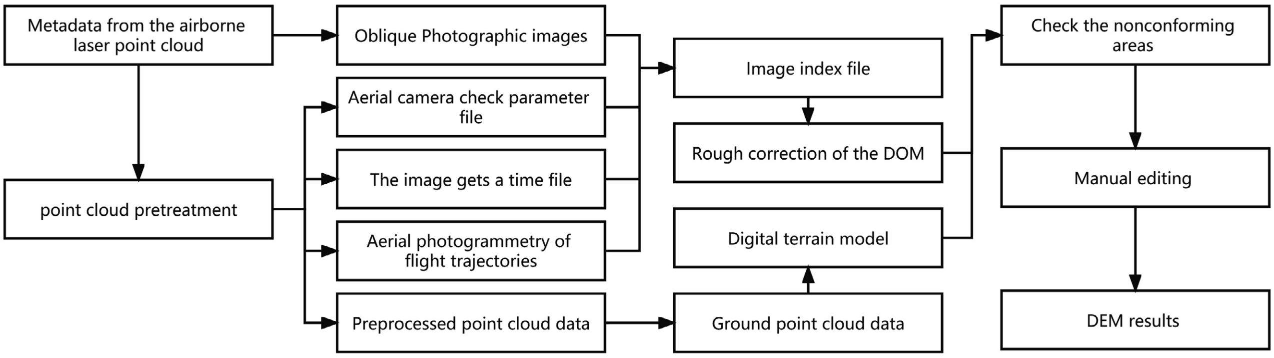

Figure 2. Schematic diagram of the production process of the digital elevation model.

4.3. Produce Building Frame Models

The building frame model is a 3D structure that represents the building in vectors, and there is no texture mapping, just the basic "skeleton" of the building, often referred to as the "white-model". The production process is first of all the use of airborne laser point cloud classification of the building class point cloud, DOM, DLG, automatically generate a rough model of the building, followed by reference to DLG, airborne laser point cloud and oblique photogrammetry image. Point cloud filtering and model correction are carried out through the Terrascan module of TerraSolid software, and the position, contour, morphology and topological relationships of some rough molds are modified. So that it meets the requirements of building frame modeling; and finally in the traditional modeling software 3ds Max optimizes model quality. A schematic diagram of the building frame model results is shown in **Figure 3**.

4.4. Extract Oblique Image Textures

Oblique imagery is to obtain the side texture of buildings, ground facilities, etc., which can effectively compensate for the shortcomings of traditional ground photogrammetry [10]. Taking oblique photogrammetry with a multi-lens Sony full-frame camera as an example, if the heading overlap is greater than 60%, 8 - 10 effective texture images can be obtained on the same figure. If the overlap reaches more than 90%, 20 - 25 effective texture images can be obtained. When tall buildings within the measurement area are obscured by themselves or influenced by each other, it is still necessary to manually photograph the hidden areas and the texture of the occluded positions on the ground [11].

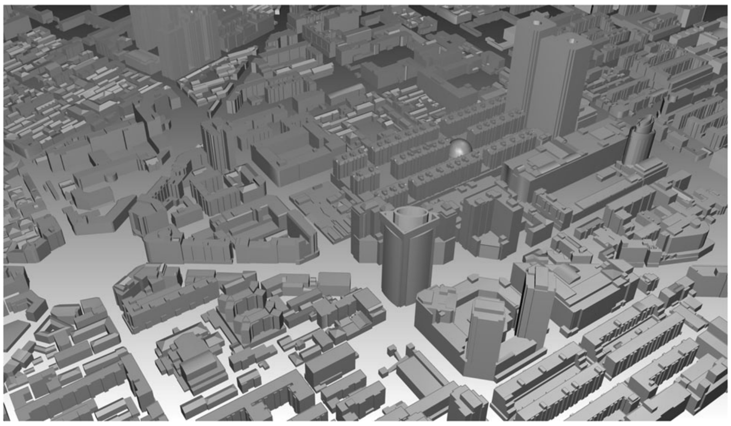

Figure 3. Schematic diagram of the results of the building frame model.

4.5. Texture Maps

In order to meet the texture mapping needs of the building side. First, fine-tune the structural details of the building frame model, such as rotating position, removing redundant surfaces, and reducing the amount of model data [12]. Second, according to the key points of the building (that is, the sign points), manually identify, match, and crop the oblique image to establish a texture mapping relationship index. Third, the crop-uniform texture is mapped to the corresponding location of the 3D building frame model [13]. After the batch automatic mapping texture is completed, if there is still deformation, distortion, pulling and other phenomena or missing situations, you need to manually find the marker points to rematch the map again [14]. Figure 4 is a schematic diagram of the results of the 3D real scene.

5. The 3D Real Scene Quality Inspection and Verification

5.1. Quality Inspection

Quality inspection is an important part of measuring whether the product results are qualified, good or bad, and the quality inspection should follow the acceptance specifications of the 3D geographic information model results [15]. The main quality inspection contents include aerial photogrammetry quality inspection, point cloud inspection, DEM elevation accuracy inspection, aerial triangulation encryption results inspection, building frame model position accuracy inspection, oblique image texture inspection, and 3D real scene effect inspection [16]. Table 2 is a checklist for building frame models in 3D real scene.

5.2. Verification of Internal and External Industries

The sampling inspection method through field and internal industry results is the current common method for verifying 3D real scene models [17], of which field inspection is mainly based on position accuracy, model texture quality and scene effect while the internal industry inspection is mainly coordinate reference system and logic. This project uses a hierarchical random sampling method, in

Table 2. 3D building frame model checklist.

Quality elements	Mass sub-elements	Check the content
Coordinate reference system	Planar datum	Check that the model conforms to the geodetic coordinate system
	Elevation datum	Check that the model conforms to the elevation datum
	Projection	Check that the projection of the model meets the requirements
Position accuracy	Plane accuracy	Check whether the difference between the plane position of the model and the location of the physical site is exceeded
	Elevation accuracy	Check whether the difference between the model elevation and the physical elevation is exceeded
Model quality	Structural quality	Check the number of out-of-limit errors between the model and the point cloud
		Examine how well locations such as the model's surface, building tops, and sides fit into the point cloud
	Texture quality	Check how closely the model fits the image and how closely it fits the image in all directions in a stereoscopic environment.
	Terrain quality	Check how well the model fits into the actual terrain
Logicality	Output format	Check whether the output of the output result is consistent, and whether the storage, naming, etc. are correct.
Scene effects	Status quo integrity	Check for redundancy of the model for noise, miscellaneous, miscellaneous, and so on.
		Check the number of missing model features. Including daughter wall, balcony, cat ear window and other structures.
	Scene shape	Check the aesthetic coordination of the model, including the undulating shape of the ground, the vertical bottom of the building and the vertical coordinate values.

Figure 4. Schematic diagram of the results of the 3D real scene.

which 10 real scene 3D building model units are sampled, and checkpoints are selected for detection. The population deviation value is calculated using the sample standard deviation as follows:

$$\Delta = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2} \tag{1}$$

In which Δ is the standard deviation, that is, the medium error; N is the sample population; x_i is the x-y plane coordinate and z is elevation value corresponding to each sample; and the mean of the corresponding coordinates of the selected sample.

Internal and external verification includes the plan location and elevation accuracy of the model building, the elevation accuracy of the road model and the ground model. In the field, we used the GNSS-RTK receiver and the total station to collect 3D coordinates of the checkpoint, and the internal industry selected the feature points as the checkpoints on the 3D real scene model to collect xyz coordinates. Table 3 shows the accuracy evaluation of the measured field coordinates at the same point and the measured coordinates of the Real 3D Scene in the models. After comparison, the medium error of the plane position and elevation of the building model ≤ ±0.6 meters, and the error in the elevation of the ground model and the road model is ≤±0.5 meters. The accuracy of the position of the building, road and ground model in the main model type of the digital real scene meets the design requirements.

The overall situation of model quality is better, and there is no deformation, blur, distortion, etc. of large-area building model. We did find any problem in the logic, the storage and naming were correct, and the output format was unified as OSGB. In terms of scene effects, we found that there were a small number of models interspersed, local cracks, surface-like loopholes, and omissions in the expression of rod-like independent figures in the edge open area.

Table 3. Real 3D scene building models accuracy evaluation table.

Check-points ID	Δx/m	Δy/m	Δz/m
CP01	−0.012	0.013	0.041
CP02	−0.016	−0.028	0.046
CP03	0.011	0.017	0.064
CP04	0.023	−0.035	0.049
CP05	−0.018	0.024	0.058
CP06	0.011	0.013	0.056
CP07	0.022	0.016	0.047
CP08	0.021	−0.019	0.035
CP09	−0.014	0.031	0.052
CP10	0.021	0.015	0.044
Average value	0.005	0.005	0.049
RMS error	0.018	0.023	0.009

6. Conclusion

This paper attempts to explore the method of using two heterogeneous data fused from on-board laser scanning point clouds and oblique photogrammetry images to produce a 3D real scene. With reference to the model quality checklist, the similarity between the 3D real scenes and the real physical world is restored to the greatest extent, which is the most suitable 3D real scenes modeling method for building a "digital city" and a "digital twins" at present. At the same time, there are some shortcomings in this method. One is that the field photogrammetry operation requires two missions, one related to the use of LiDAR equipment to obtain point clouds, and the other related to the multi-lens oblique camera to obtain multi-angle images, increasing the project investment and construction costs. The second is that, compared with the traditional 3dsMax manual modeling, the operation cycle of multi-source heterogeneous data fusion modeling is saved by about 20% - 30%. However, by comparing with the use of only oblique image modeling operations, the data pre-processing, air-three achievement fusion, human-computer interaction and other links are more time-consuming. The total modeling cycle increased by about 50%. Therefore, when constructing a 3D real scene, it is necessary to choose a balanced and suitable 3D digital modeling method, according to the multiple factors based on the project cycle, operation efficiency and cost inputs.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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