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Research and Application of Normalized Update Method for Urban-level 3D Real Scenes

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With the continuous advancement of the construction of 3D real scenes in China, urban-level 3D real scenes have been built in various parts of the country, and integrated applications have been carried out in various industries. To better support economic and social development and assist in the construction of a digital government and digital China, it is necessary to update the urban-level 3D real scenes to ensure their timeliness. In this paper, we focus on the characteristics of the tile-based modeling of urban-level 3D real-scene data, using data from daily urban surveying and dynamic monitoring using unmanned aerial vehicles to quickly obtain a tilted mesh model. By unifying the coordinate origin and grid size, we can regularly update the urban-level 3D real scene data, forming a mechanism for the regular update of urban-level 3D real scene data. It has been comprehensively applied in the maintenance and update of the urban-level 3D real scenes in Wuhan, solving the problems of low efficiency, high cost, large color difference, and poor effect at the update range of urban-level 3D real scene data.

1. Introduction

A national 3D real scene is spatiotemporal information that reflects and expresses the ecological space of production and life in a realistic, 3D, and temporal manner. It is the core element and important content of the overall framework construction of digital China.[(1)] Since 2023, the Ministry of Natural Resources has successively issued policy documents such as the "Overall Implementation Plan for the Construction of National 3D Real Scene (2023–2025)" and the "Opinions of the Ministry of Natural Resources on Accelerating the Transformation and Upgrading of Surveying and Mapping Geographic Information Industry to Better Support High-quality Development." Multiple work promotion meetings have been held, requiring the promotion of the construction of the national 3D real scene, creating a unified spatiotemporal

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foundation for the construction of digital China, supporting natural resource management, government management decision-making, and digital economic development, and improving people's lives, the digital culture, and ecological civilization construction.[2]

3D real scenes are divided into terrain level, urban level, and component level. Among them, the urban-level 3D real scene provides a bird's-eye view of the urban landscape from a meso perspective,[3] emphasizing the fine expression of buildings, residential areas, public places, and their ancillary facilities, and facilitating the fine management and overall planning of a city. It mainly relies on oblique photography methods for modeling to better achieve the digital mapping of production and living spaces (urban spaces),[4,5] which is the core work of 3D real-scene construction. Urban-level 3D real scenes have achieved good application results in urban planning approval, ecological environment restoration, urban renewal, urban management, carbon measurement services, disaster monitoring, community governance, and other aspects. However, as cities continue to develop and change rapidly, how to ensure the timeliness of large-scale urban-level 3D real scenes is an urgent problem that needs to be solved.[6] The traditional update approach is to establish a special project for overall regional updates. This method does not achieve precise updates of changed areas, and the update efficiency is low, the cost is high, and the update cycle is long, which cannot adapt to and meet the application needs of urban-level 3D real scenes.

In this study, we take into account the advantages of unmanned aerial vehicles in obtaining tilted mesh models, such as small spatial limitations, high flexibility, low cost, and high acquisition efficiency. A large number of tilted mesh models, which are collected and produced in daily urban surveying and dynamic monitoring processes,[7] can be used as an update data source to carry out urban-level 3D real scene dynamic update work.

2. Method

An urban-level 3D real scene is generally produced in batches, with a long total production cycle and inconsistent production platforms for each batch, resulting in differences in data organization structure and the inconsistent origin of data results among different batches. This leads to duplicate naming when different batches of results are gathered together, making it difficult to effectively manage. To achieve normalized updates of urban-level 3D real scene data and avoid the problems of high cost, long time, and low efficiency caused by traditional regional overall updates, in this study, we fully utilized the unmanned aerial vehicle tilted mesh model formed by daily urban surveying and dynamic monitoring to propose the idea of urban-level 3D real scene grid update. By unifying the coordinate origin and grid size, we can eliminate the spatial overlap and naming duplication of tile data between different batches of data results. During the data update process, the tile data involved in the changed area can be directly updated quickly, achieving the "dual-use" of tilted mesh model results. The updated technology roadmap of an urban-level 3D real scene is shown in Fig. 1.

2.1 Production of tilted mesh model

Generally, the changed areas of an urban-level 3D real scene are irregular and often inconsistent with the unified grid division, resulting in overlapping, intersecting, and other

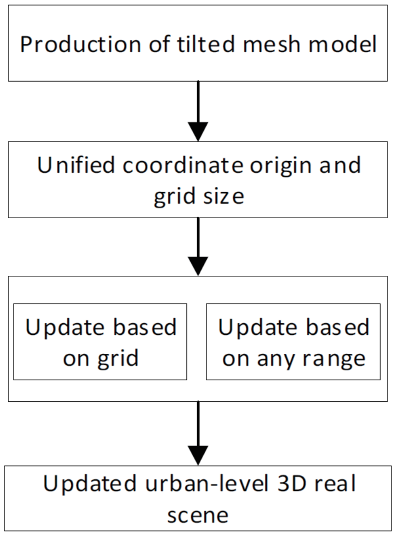

Fig. 1. Update idea for urban-level 3D real scene.

situations between the changed areas and the unified grid. To ensure the integrity and usability of the tilted mesh model results in the changed areas, all grid areas related to the spatial correlation of the changed areas need to be taken as the data production range during data production, and unmanned aerial vehicles are used for tilted photogrammetric modeling[(8,9)] to produce tilted mesh models. As shown in Fig. 2, the changed area is within the red line and the data production range is in the blue area.

2.2 Unified coordinate origin and grid size

To update the existing urban-level 3D real scene based on production tilted mesh models, it is necessary to unify the coordinate origin and grid size. The coordinate origin can be set as the geometric approximate center of the urban-level 3D real scene coverage area, and the grid size can be set to "100 meters × 100 meters" according to production and management requirements. As shown in Fig. 3, the unified coordinate origin of the area of Wuhan City is established and a grid is divided.

2.3 Data update

For the organization and management of urban-level 3D real scenes in tile files, the update methods mainly include grid-based and any range-based updates.

2.3.1 Update based on grids

The update based on the grid of the urban-level 3D real scene is performed to replace all the grid tile files where the changed area is located with the grid tile files corresponding to the tilted mesh model produced and to complete the color matching and edge joining work on both sides of the changed area. This method will synchronously update the unchanged areas in the same grid,

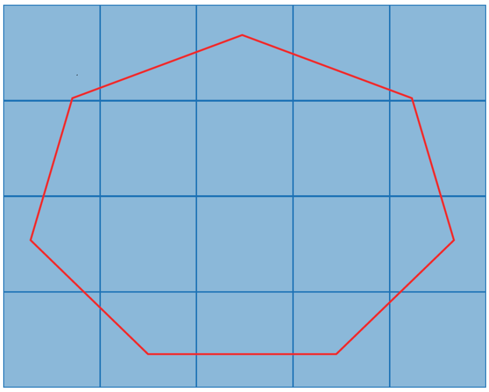

Fig. 2. (Color online) Schematic chart of changed area and data production range.

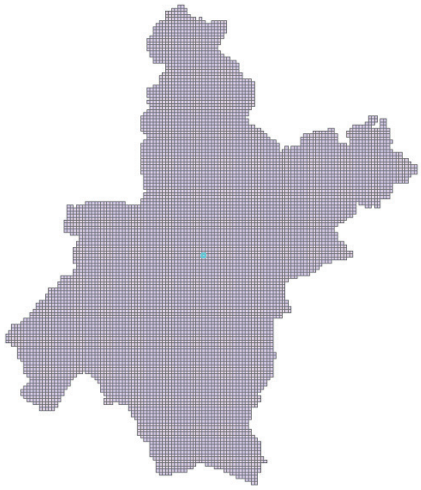

Fig. 3. (Color online) Unified coordinate origin and grid size in Wuhan.

but the actual update range is often inconsistent with the changed areas. The specific update process is shown in Fig. 4.

2.3.2 Update based on any range

On the basis of the tilted mesh model produced, the actual update range is determined. On the basis of this range, the tilted mesh model and the urban-level 3D real scene to be updated are cropped. The tilted mesh model inside the cropped range is fused with the urban-level 3D real scene to be updated outside the range.(10,11) By reconstructing the triangular mesh, model reconstruction,(12,13) texture mapping,(14–16) and uniform light and color reconstruction(17) near the update range, we can complete the update of urban-level 3D real scenes(18) based on any range. This method can achieve precise updates of changed areas with little impact on areas that have not changed.

The key to this method lies in determining the update range. Therefore, when determining the update range, it is necessary to first ensure that the range is located in an unchanged area, ensuring that there is no difference between the new and old 3D models at the junction position. Second, the texture at the location of the range should be relatively uniform to avoid texture misalignment or inconsistency during edge fusion Third, the range should minimize the occupation of unchanged areas to ensure the accuracy of updating the range. The specific update process is shown in Fig. 5.

3. Experimental Results

By the end of 2022, Wuhan City has built the urban-level 3D real scene covering nearly 2000 square kilometers in the central urban area, Yangtze River New Area, Economic Development Zone, and Donghu High-tech Zone. With the continuous development of urban construction, the

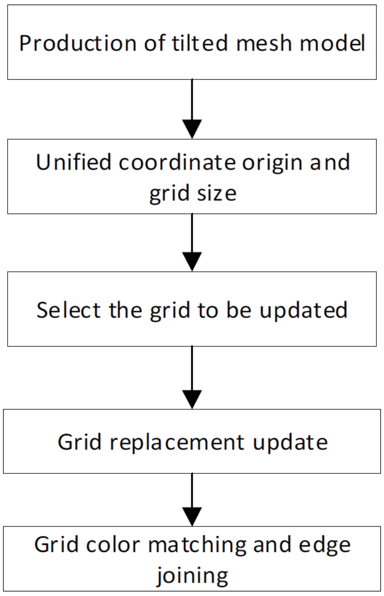

Fig. 4. Flow chart of urban-level 3D real scene update based on grids.

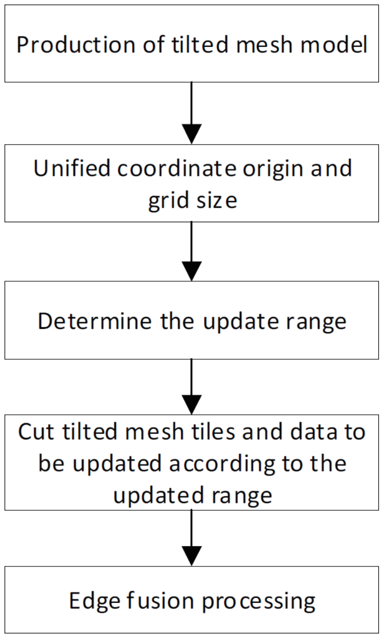

Fig. 5. Flow chart of urban-level 3D real scene update based on any range.

existing urban-level 3D real scene urgently needs to be updated. In this study, we selected two areas where significant land changes have occurred, used daily urban surveying and dynamic monitoring unmanned aerial vehicles to produce tilted mesh models, and conducted data update experiments using grid-based and any range-based urban-level 3D real scene update methods.

3.1 Update experiment based on grids

Using an unmanned aerial vehicle to carry out urban completion surveying and mapping projects for a residential community as an example for updating an urban-level 3D real scene, we verified the correctness and rationality of the update method based on grids. We quickly obtained the tilted mesh model of the area where the residential community is located, as shown in Fig. 6.

The urban-level 3D real scene corresponding to this area is shown in Fig. 7. We unified the coordinate origin and grid size of the model and then selected the grid to be updated from the tilted mesh model, as shown in Fig. 8. We replaced and updated the data files corresponding to the grid, and completed color matching and edge joining, as shown in Figs. 9 and 10.

3.2 Update experiment based on any range

Taking unmanned aerial vehicles to conduct the inspections and dynamic monitoring of illegal buildings to update the urban-level 3D real scene as an example, we verified the correctness and rationality of the update method based on any range. We quickly obtained a tilted mesh model of illegal buildings by a lake in a certain scenic area, as shown in Fig. 11.

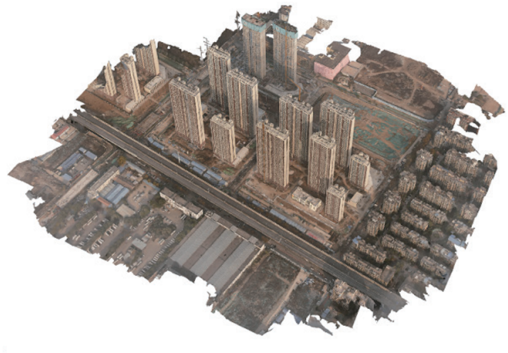

Fig. 6. (Color online) Tilted mesh model around a residential community.

Fig. 7. (Color online) Urban-level 3D real scene corresponding to the location of a residential community.

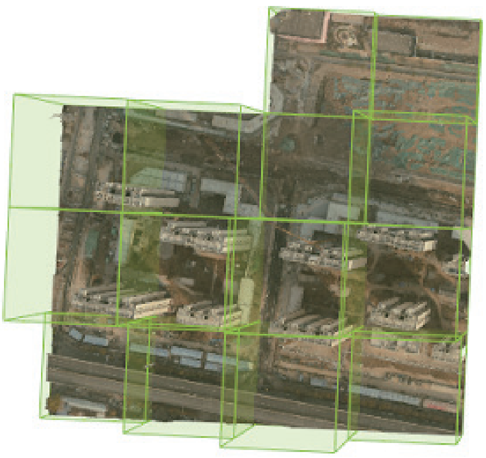

Fig. 8. (Color online) Select the grid to be updated.

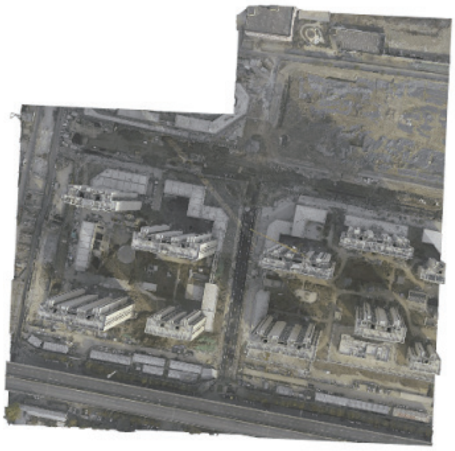

Fig. 9. (Color online) Color matching and edge joining of data files corresponding to the grid.

Fig. 10. (Color online) Updated urban-level 3D real scene with grid replacement.

Fig. 11. (Color online) Tilted mesh model of illegal buildings by a lake in a certain scenic area.

The original urban-level 3D real scene corresponding to this area is shown in Fig. 12. We unified the coordinate origin and grid size of the model, and then determined the update range from the tilted mesh model, as shown in Fig. 13. We cut the tilted mesh model and the urban-level 3D real scene to be updated on the basis of the updated range, as shown in Figs. 14 and 15. Finally, the cropped data was subjected to edge fusion processing to form an updated urban-level 3D real scene, as shown in Fig. 16.

Fig. 12. (Color online) Original urban-level 3D real scene corresponding to illegal buildings.

Fig. 13. (Color online) Determination of the update range.

Fig. 14. (Color online) Trimmed tilted mesh model.

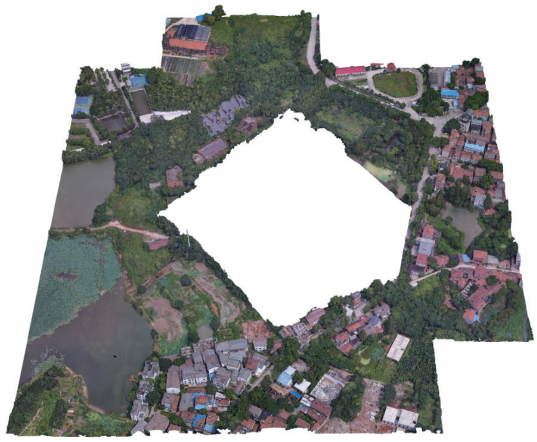

Fig. 15. (Color online) Trimmed urban-level 3D real scene to be updated.

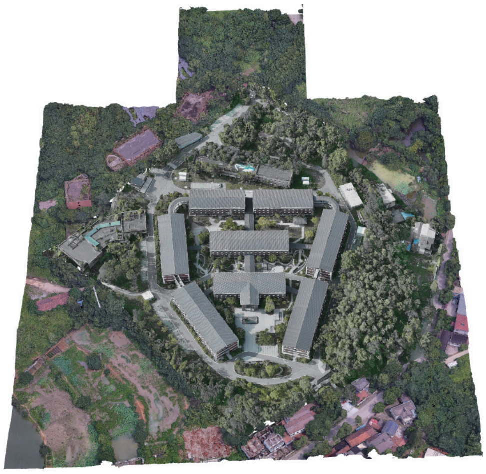

Fig. 16. (Color online) Urban-level 3D real scene after edge fusion.

4. Discussion

Through the above experiments, it can be seen that with the tilted mesh model formed by daily urban surveying and dynamic monitoring, the normalization of urban-level 3D real scene updates has achieved good integration and update effects. Not only has it fully utilized existing urban surveying and dynamic monitoring data, but it has also formed a set of urban-level 3D real scene update technology solutions, greatly reducing update costs and shortening update cycles, providing reference ideas for other cities to carry out urban-level 3D real scene updates.

5. Conclusions

With the continuous acceleration of the construction process of the national 3D real scene, increasing numbers of provinces and cities have completed the construction of their urban-level 3D real scenes mainly in the form of tilted mesh models. The management, updating, and application of urban-level 3D real scenes are important tasks currently facing us. The current trend of urban-level 3D real scenes is also an important factor affecting its promotion and application. To solve the issues of high cost, low efficiency, and time-consuming traditional large-scale overall updates, we combined the results of tilted mesh models formed by daily urban surveying and dynamic monitoring to propose a grid-based update idea for urban-level 3D real scenes, realizing the methods of updating the urban-level 3D real scenes based on grids and any range. Through case verification, good update effects have been achieved. This provides a useful reference and inspiration for the normalization of urban-level 3D real-scene updates.

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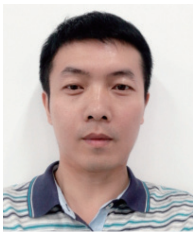

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