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Construction and Information Interaction Visualization of Digital City Model Based on UAV Oblique Measurement Technology

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Abstract. This paper addresses the challenges of significant discrepancies between model data and real building data, as well as the limited visualization of data information interaction during the construction of digital city models. A technical solution leveraging unmanned aerial vehicles (UAVs) for oblique photogrammetry is proposed. The solution systematically outlines four critical processes: data acquisition, aerial triangulation, dense matching, and model construction. In the data acquisition phase, the working environment of UAVs is thoroughly analyzed, with detailed descriptions provided for parameter settings and flight measurement schemes. For data visualization, the approach integrates Building Information Modeling (BIM), Geographic Information System (GIS), traffic simulation, and real-scene 3D technologies to enhance the representation of spatial data. Through methodological analysis, the feasibility of the proposed solution is validated from the perspective of data accuracy. To demonstrate practical application, a microcosm of a digital city, a digital campus, is selected. By incorporating real-scene 3D technology, an accurate simulation and visualization of the campus environment are achieved. Finally, the feasibility of the proposed method is confirmed through a comparative analysis of model error precision.

Keywords: oblique photogrammetry, visualization, digital city, BIM

1 Introduction

With the advent of the era of artificial intelligence and big data, as well as the rapid development of new information technologies, a series of "new urban" concepts have emerged, such as digital cities, smart cities, and digital twin cities [1]. Digital twin cities represent a new height in the construction of smart cities. Through digital twin technology, digital twin cities provide an integrated digital platform for the planning, design, and construction of smart cities. This platform can simulate the operational status of the city, significantly enhancing the refinement of urban design. Its core concept lies in achieving comprehensive monitoring, in-depth analysis, and intelligent optimization of objects, systems, or processes through digital modeling of the real world. With the help of digital twin city models, urban planners, government decision-makers, and citizens can gain deeper insights into the dynamics of urban development, optimize urban spatial layouts, enhance urban safety, and promote the intelligent and sustainable development of the city [2].

The construction of digital twin cities requires the deep integration of real-scene 3D technology. Real-scene 3D technology achieves high-precision modeling of cities by integrating multiple information technologies such as 3D models, Building Information Modeling (BIM), and City Information Modeling (CIM). This technology can integrate multi-source data and support the analysis, simulation, and visualization processing of these data. Moreover, the modeling process of digital twin cities relies on the support of various data collection devices and professional modeling software. However, in the traditional data collection stage of city models, due to insufficient data synchronization capabilities, there is a significant error between the building dimensions in the model and the actual building dimensions. With the rapid development of oblique photogrammetry systems and aerial photography technology, the error between the model and the physical object has been significantly reduced.

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Oblique photogrammetry technology not only improves the efficiency of 3D model reconstruction but also effectively reduces the cost of urban 3D reconstruction and enhances the model accuracy. Therefore, oblique photogrammetry technology based on unmanned aerial vehicles has become an important means to obtain large-scale high-precision 3D information [3].

Oblique photogrammetry technology can provide high-resolution, multi-angle and highly stereoscopic image data of buildings, effectively reflecting the facade and detailed features of buildings. However, due to the inherent limitations of this technology, the generated models lack internal information of buildings. Therefore, to obtain complete internal information of buildings, oblique photogrammetry technology needs to be combined with other modeling methods to achieve comprehensive improvement of building model information. In contrast, traditional BIM technology can achieve integration and coordination in various stages such as 3D modeling, construction and management of buildings, and contains rich building data information. More importantly, BIM technology can precisely express the three-dimensional spatial relationships of various objects inside buildings through data [4].

This paper mainly explores the modeling methods of digital twin cities and the detailed description of the modeling process. In the stage of obtaining urban model data, oblique photogrammetry technology is adopted for data collection. The modeling method of oblique images is essentially an automatic modeling method based on data-driven, although its degree of automation is relatively high, there are still some limitations that are difficult to overcome in the later management and application of the model. Urban spatial visualization technology is based on computer graphics, multimedia technology and geographic information systems, and integrates 3S technology (remote sensing, global positioning system, geographic information system) and virtual reality technology to achieve multi-resolution and multi-scale modeling and rendering of urban spatial data. By combining oblique photogrammetry technology and 3D visualization methods to optimize the research on urban spatial digital models, not only can the visualization expression of urban 3D data models be effectively realized, meeting the integrated visualization requirements of 3D data models, but also the operational efficiency of 3D systems can be significantly improved, providing support for building more efficient 3D urban visualization systems. In addition, this research can provide important reference value for improving data operation efficiency and optimizing visualization effects in the process of visualizing urban multi-source data.

The work done in this paper is as follows:

1) The method of unmanned aerial vehicle (UAV) oblique measurement was analyzed. The process was described in detail from four main aspects: data acquisition, aerial triangulation, dense matching, and model construction. Through this process, a certain university was used as the actual measurement object to complete the construction experiment of some models.

2) In the visualization process of the model, the overall technical solution of the information visualization platform was constructed, and the teaching and management data of a certain university in Xingtai were imported to realize the construction experiment of some functions of the digital twin city. Then, based on the visualization technical solution, the pseudo-code of the construction process was provided.

3) This paper mainly describes the methods and selectively omits the actual construction process. In the final verification section, the method of this paper is described from the aspect of reducing data errors.

2 Related Work

This section summarizes the existing research results from several aspects, including UAV oblique measurement, digital city models, and information interaction visualization. In the field of UAV oblique photogrammetry, Yanyan Xing, based on the technical characteristics of UAV oblique photogrammetry, constructed a three-dimensional virtual landscape system. Then, an improved convolutional neural network was designed on the TensorFlow platform for feature extraction of green landscapes, achieving an extraction accuracy of 96.36% [5]. Wenping Fan from Shandong Jianzhu University proposed a method for autonomous roaming with collision detection based on UAV oblique photogrammetry technology. The method is based on real three-dimensional models and combines human-computer interaction and control scripts for functional implementation. Finally, a virtual campus roaming system was constructed, and after testing, it was found that the coordinate error was within a reasonable range [6].

In terms of the construction of digital city models, Shukui Wang took Nanjing as the target object, fully utilized the existing data resources, and divided the three-dimensional digital framework model of the city into five categories, namely basic model, detailed model, functional model, control model and scheme model, according to the needs of different application scenarios of smart city governance. He systematically constructed the three-dimensional digital base plate of the urban spatial framework [7].

Chun Wang, in the process of building a digital city, analyzed the defects of CAD models involved in the city model, proposed the calculable conditions to be met and the corresponding processing methods, which could directly generate a calculable city model without CAD model defects. At the same time, in order to improve the efficiency of calculable processing, he also proposed a fast graphic retrieval algorithm for large-scale cities [8].

In the field of information interaction visualization, He Tang, taking the operation of power grid distribution as the scenario, combines the SCADA system with the intelligent distribution network automation system and adopts the integrated EPON and industrial Ethernet technology to establish a distribution network visualization platform. The system is developed based on the JAVA platform and collects distribution network operation parameters, controls equipment, adjusts parameters, and issues various information alarms through a fully distributed SCADA subsystem, thereby enhancing the level of power grid distribution management [9]. Ke Cheng proposed an implementation method for mapping IFC model data to a database, reconstructing BIM on the Web, and conducting online visualization analysis of information. This method utilizes a Web framework to build an application for mapping IFC standard files to a relational database. The framework uses the JavaScript language to deeply parse IFC standard files, achieving the completeness and efficiency of project data visualization interaction [10].

In summary, this paper, through analysis, proposes the construction process of a digital city model based on UAV oblique measurement technology, and simultaneously discusses the visualization methods for urban information interaction. The composition structure of this paper is as follows:

The second section primarily reviews related research. The third section discusses the data collection methods used in architectural model construction. The fourth section focuses on methods of visual interaction. The fifth section outlines the improvements made to enhance data accuracy in this approach. The final section provides a conclusion, summarizing the research findings and suggesting directions for future research.

3 Acquisition of Building Model Data

The models required for building an interactive visualization system for buildings can be divided into two major categories: one is the real three-dimensional model of the building, mainly including the external contour of the building, terrain, greenery, etc., and the other is the BIM. The real three-dimensional model of the building mainly provides a real physical environment for the interactive visualization system. It has a higher degree of restoration in features such as model texture and terrain undulation, making the user’s immersion stronger. Its highly automated modeling method meets the requirements for restoring large areas of buildings and their surrounding environments. The reconstruction of real three-dimensional models based on oblique photography technology mainly consists of two parts: the field data collection work and the indoor processing work of oblique photogrammetry data [11].

Oblique photogrammetry refers to the collection of ground image data from multiple angles. After indoor processing, accurate and complete information and texture data of ground objects are obtained, which makes up for the shortcomings of traditional orthophoto aerial photography in obtaining effective information on the sides of high-rise buildings and some occluded areas [12].

3.1 Technical Route of Oblique Photogrammetry

The construction of large-scale real-scene models of cities based on oblique images involves data acquisition, free network adjustment of aerial triangulation, bundle adjustment of aerial triangulation with control points, generation of dense point clouds, TIN construction, texture mapping, and model correction. On this basis, this paper mainly realizes four key links: data acquisition, aerial triangulation, dense matching, and model construction [13]. The specific technical route is shown in Fig. 1.

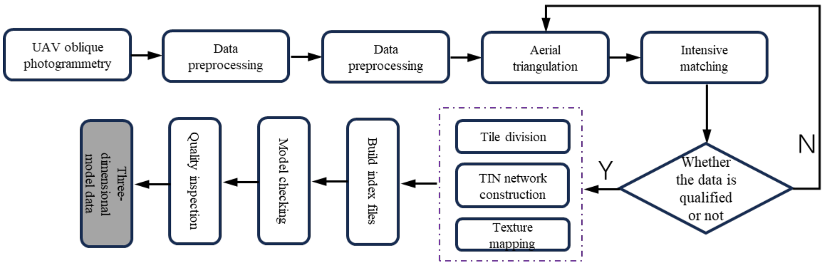

Fig. 1. Technical roadmap for oblique photogrammetry

Before conducting large-scale UAV aerial photography, it is necessary to complete the flight path planning based on the area of the survey zone, geographical environment, and remote sensing maps, and use an automatic or semi-automatic navigation system for aerial photography. The research area of this study is a certain institution in Xingtai City, and the equipment parameters are shown in Table 1, The shooting parameters are set as shown in Table 2.

Table 1. Equipment and parameters used for data collection

Equipment name	Brand and parameters
UAV model	DJI Phantom 4 RTK Canon EOS M3
Camera	40mm f/2.8, STM lens
Lens	5472×3648 pixels
Image acquisition size	5.97um
Pixel size	24.27mm
Focal length	DJI Phantom 4 RTK Canon EOS M3

Table 2. Flight parameter settings

Shooting parameters	Shooting parameter settings
Average flight altitude	29 m
Ground sampling distance	0.8cm/pix
Flight speed	3.9m/s
Photo-taking mode	The fixed-distance shooting method
Course overlap rate	80%
Flight mission	Five sorties
Flight time	59min15s
Number of photos taken	1008
First flight altitude	14.2m
Camera angle (downward)	44°
Second flight altitude	10.1m
Camera angle	0
Third flight altitude	6.7
Camera angle (upward)	45°
Overlap degree of supplementary photos	78%
Number of photos not taken	189

3.2 Data Acquisition

During the process of obtaining data through aerial photography with drones, the best exposure parameters of the camera were adjusted. The forward overlap and side overlap should not be less than 80%. A total of 473 oblique images were obtained for the entire area. After the flight, the obtained aerial photos were sorted by flight time in batches. Each batch file should contain the aerial photos and the corresponding POS data. The layout of the experimental control points followed the principle of “uniform distribution and corner point layout”. A total of 6 control points were set on the ground to control the survey area, and 2 check points were set to check the overall accuracy of the survey area. The coordinates of the control points were obtained by using the fixed smoothing collection of the HXRTK. The coordinate system of the control points adopted the Xingtai City Coordinate System, with the central meridian at 115°15 and 6.78", and the elevation coordinate system adopted the 1985 National Elevation Benchmark [14]. They were respectively set at the road markings, covering the entire survey area. The layout of the control points is shown in Fig. 2.

Fig. 2. Layout diagram of aerial photography points for aerial photography operations

The red circles represent the positions of the control points, and the blue triangles represent the positions of the check points. Three control points are designed for the target area and are evenly distributed within it. Each control point is observed twice, with an observation time of no less than 20 epochs. The interval between the two observations is 2 to 5 seconds. The average value of the two observations is taken as the coordinate of the control point.

3.3 Aerial Triangulation

Aerial triangulation refers to the solution of the ground coordinates of unknown points within a survey area based on a few control points as constraints, following the principle of least squares [15]. The outcome directly affects the quality of the mapping and the mathematical accuracy. According to the mathematical models adopted in aerial triangulation, it can be classified into strip adjustment, independent model adjustment, and bundle adjustment. As bundle adjustment does not process stereo pairs separately but builds a large geometric network encompassing all images and enhances the accuracy of aerial triangulation through global optimization, it is suitable for large-scale and high-precision mapping projects and has gradually become the primary adjustment method for aerial triangulation. Bundle adjustment involves taking the camera’s pose and the world coordinates of the points to be measured as unknown parameters, and using the feature point coordinates obtained from the images for forward intersection as observation data to perform adjustment and obtain the optimal camera parameters and world point coordinates. Bundle adjustment is based on the collinear equation as the mathematical model, where the observed image plane coordinates of the image points are nonlinear functions of the unknown parameters. After linearization, the calculation is carried out according to the principle of least squares. This calculation is also an iterative method that starts from an approximate solution to approach the optimal value step by step [16]. A schematic diagram of bundle adjustment is shown in Fig. 3.

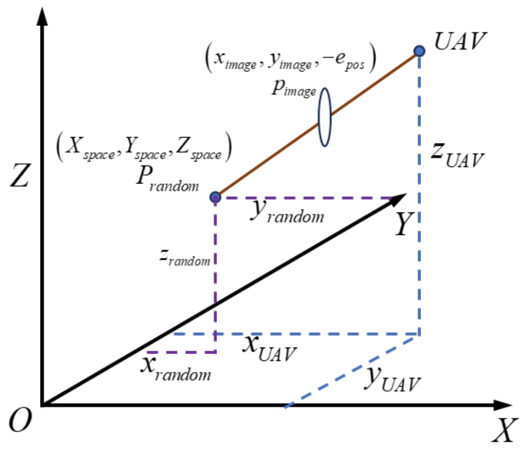

Fig. 3. Schematic diagram of the principle of beam adjustment method

As shown in the figure, UAV in the figure represents the unmanned aerial vehicle (UAV) during the shooting work, which is the photography center. Its world coordinate system is denoted as (x_{UAV}, y_{UAV}, z_{UAV}). P_{random} is any point in space, and its coordinate in the world coordinate system is denoted as (x_{random}, y_{random}, z_{random}). P_{image} is the image of P_{random} on the image, and its image plane and image space auxiliary coordinates are denoted as (x_{image}, y_{image}, $-e_{pos}$) and (X_{space}, Y_{space}, Z_{space}) respectively. The transformation matrix can be obtained as:

$$\begin{bmatrix} x_{image} \\ y_{image} \\ -e_{pos} \end{bmatrix} = \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix} * \begin{bmatrix} X_{space} \\ Y_{space} \\ Z_{space} \end{bmatrix} \tag{1}$$

From the above two equations, the collinearity equation can be obtained:

$$\begin{cases} x - x_0 = -e_{pos} \dfrac{a_1(x_{UAV} - x_{random}) + b_1(y_{UAV} - y_{random}) + c_1(z_{UAV} - z_{random})}{a_3(x_{UAV} - x_{random}) + b_3(y_{UAV} - y_{random}) + c_3(z_{UAV} - z_{random})} \\ y - y_0 = -e_{pos} \dfrac{a_2(x_{UAV} - x_{random}) + b_2(y_{UAV} - y_{random}) + c_2(z_{UAV} - z_{random})}{a_3(x_{UAV} - x_{random}) + b_3(y_{UAV} - y_{random}) + c_3(z_{UAV} - z_{random})} \end{cases} \tag{2}$$

In the equation, x_0, y_0, and $-e_{pos}$ represent the interior orientation elements with images, indicating the coordinates of the image plane center and the camera's principal distance. The collinear equation is linearized by performing a first-order Taylor expansion on it, and at the same time, an error equation in matrix form is constructed. The equation is expressed as:

$$Error = \begin{bmatrix} M & N \end{bmatrix} * \begin{bmatrix} X \\ t \end{bmatrix} - L \tag{3}$$

In the formula, L represents the actual linear length of the target, denoted as $L = [l_x \ \ l_y]^T$. M and N are the error coefficient matrices, t represents the increments in three directions, and X represents the measured coordinates. Solve the normal equation for the error correction numbers and the normal equation for the correction numbers of the undetermined point coordinates. When the correction numbers are less than the limit difference, the aerial measurement of the target is completed; otherwise, continue the iteration until they are less than the limit difference.

The study area of this paper is located in an inland urban agglomeration, far from the sea and other special and complex geographical environments. The image data collected in the field will be affected by factors such as lens exposure, camera distortion, and atmospheric refraction, which will affect the image quality. Before performing aerial triangulation, the data needs to be screened to reduce the influence of factors such as sensors, exposure, and wind force. In the preprocessing stage of this experiment, the lens was calibrated first to eliminate the influence of lens distortion. The Capture One software was used to perform uniform light and color processing on the selected images, adjust the exposure of problematic images, and unify the tones of aerial and ground supplementary photos, the shooting principle is shown in Fig. 4.

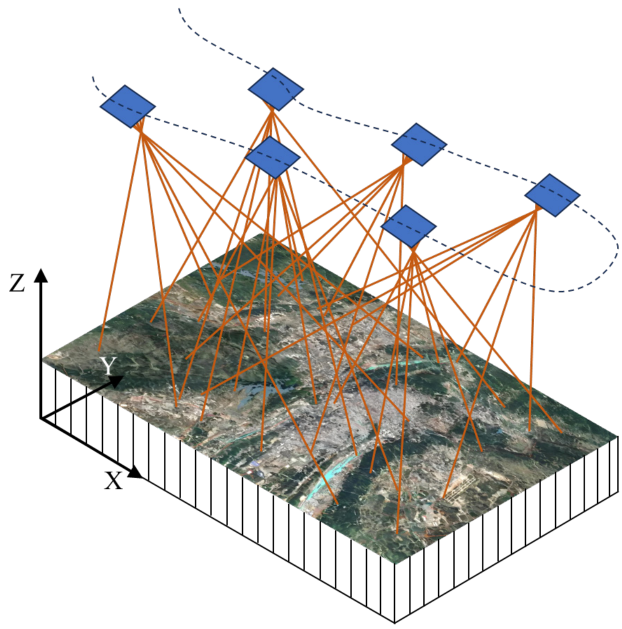

Fig. 4. Schematic diagram of the principle of beam adjustment method

Based on the coordinate system of the ground control points, the spatial reference system is selected. Manually, based on the homonymous ground control points and the field control point data, the homonymous ground control points are precisely marked on multiple images to provide the real coordinate system coordinates for the regional network adjustment. The overall coordinates are then transformed to the target coordinate system. To ensure the accuracy of the point marking, each ground control point should be marked on 16 to 25 images, and 3 to 5 images should be marked for each angle. Points that are unclear or located at the edge of the image should be avoided as much as possible. After the point marking work is completed, the regional network adjustment calculation is carried out again. According to the aerial triangulation report and the point position prediction of the unmarked images, the points with a prediction deviation of more than 3 pixel values are checked. For points with large gross errors, re-marking is carried out, and this process is repeated multiple times to eliminate the rough points [17].

3.4 Intensive Matching

Since both photogrammetry and multi-view geometry involve using images to obtain the three-dimensional structure of the real world, and multi-view geometry does not require the constraints of prior knowledge, dense matching based on multi-view has become the focus of research in photogrammetry. Among them, patch-based multi-view stereo refers to the local tangent plane of the three-dimensional object surface. Its principle is that a three-dimensional space rectangle is determined by the center point, the unit normal vector, and the reference image. PMVS [18] selects known ground points as initial seeds, creates patches around each seed, and then attempts to match and expand the patch in other images. For each initial patch, the angle between the image line of sight and the patch normal direction is calculated for visual analysis. Then, the consistency of the patch in all visible camera views is evaluated to determine if it meets the multi-view geometry constraints. Through the continuous repetition of the patch expansion process, PMVS gradually builds the three-dimensional structure of the entire scene. The specific steps are as follows:

(1) Epipolar constraint: For each feature point in the image, an array is associated, which includes all feature points on the same epipolar line in the image.

(2) Forward intersection: Select a feature point from the associated array to form a pair of corresponding image points, and calculate the three-dimensional coordinates of the object point through forward intersection.

(3) Point to patch: The direction of the line connecting the object point coordinates and the photographic center is used to construct the unit normal vector.

(4) Determine the visible set: The visible set is determined by the angle between the line connecting the object point and other photographic centers and the unit normal vector.

(5) Optimize patch pose: Minimize the total imaging difference function of the patch as the goal, and correct the position and orientation of the patch through the conjugate gradient method.

(6) Expand the patch: Build the three-dimensional structure of the entire scene.

(7) Remove gross error patches: Filter out patches with discontinuous visible information.

3.5 Model Reconstruction

Model reconstruction mainly proceeds on the basis of the data obtained in the above-mentioned several steps for model construction. Based on the dense matching algorithm of the Keanjing Smart3D software [19], the GPU is called to perform rapid operations on the scene, obtaining ultra-high-density dense point clouds and digital surface models of the study area. The ultra-high-density point clouds generated by dense matching are set with thresholds, and triangular networks are constructed through different levels. The TIN model is ultimately generated based on the curvature changes between the triangular networks. By finding the Obj file corresponding to the light and shadow problem, the problem texture is modified through the Photoshop software and rolled back to solve the texture problem. For the model structure problem caused by obstacles blocking, the problem tiles are edited with irregular triangular networks and the texture is rolled back to achieve the repair of the model structure problem. Finally, a fine real-scene 3D model is obtained, achieving the purpose of more realistic visualization interaction.

The above process discusses the data acquisition process for digital city building models. This paper provides a method for data acquisition. During the data acquisition process, a university where data acquisition is relatively convenient was selected. The error in data acquisition will indicate the feasibility of the method proposed in this paper. After data acquisition, the model is constructed through aerial triangulation, dense matching, and model building. The next step is to link the model and data. In the early stage of building construction, the BIM method has already collected and included some building information. Therefore, the purpose of this paper is to achieve the connection between the digital model and building data and to realize data visualization. Further, the method of data visualization will be discussed in the next chapter.

4 Visualization Model Construction

In the process of digital city construction, the visualization platform for real-scene 3D simulation is an indispensable and important tool in the innovative development of smart cities. This platform can not only be used to enhance the decision-making ability of campus management but also promote intelligent energy conservation on campus. Taking efficient digitalization in digital cities as an example, this paper specifically takes campus digitalization as the actual experimental scene, integrating data on campus buildings and campus networks and other equipment, with the aim of constructing a unified spatiotemporal benchmark and interactive real-scene base map. On this basis, through the construction of a digital campus, the entire process of data collection, simulation, management, application, analysis and display of campus scenes is realized, forming a comprehensive campus management solution integrating functions such as campus scene simulation, data visualization and decision support [20].

4.1 Construction of Visualization Framework

During the process of creating the visualization model, ContextCapture [21] was used for the construction of the

3D model. To use ContextCapture for this purpose, a new project needs to be created, and all the remote sensing images obtained from the oblique photography of the UAV as well as the initial exterior orientation elements obtained from the airborne POS system should be imported. The best photos should be selected for point matching and added to the control point coordinate system. The exterior orientation elements solved by aerial triangulation are used to establish the stereo relative. ContextCapture will generate a high-density 3D point cloud through multi-view image dense matching, automatically matching the homonymous points in all image data, and more finely display the details of real ground objects. In the specific operation of the ContextCapture software, due to the large shooting range and the need to process a large amount of image data, the computer's running memory required for completing the modeling is large, and a general computer cannot complete the calculation task at one time. The shooting parameters during the flight process are described in Section Three. The 3D campus model constructed by ContextCapture has some unattractive details, such as uneven model surfaces, missing texture information in large water areas, floating models, missing components, buildings sticking together, and holes. The reasons for these defects are often due to the influence of weather during the UAV flight, some errors caused by human factors during the operation, and the difficulty in matching homonymous points due to the mirror reflection of smooth surfaces of buildings and water bodies, resulting in component loss and holes.

4.2 Data Import

After completing the visualization model, the file needs to be exported. The minimum hardware configuration of the server to be deployed is determined based on the memory and graphics memory occupied by the project. The exported file is copied to the deployed server, system parameters are adjusted, and the server's graphics card, monitor, and power supply, etc. are configured properly to prevent the visualization model from running unsmoothly due to improper computer system settings. Finally, the file is imported to run the data and the three-dimensional space integrated visualization model. The deployment diagram is shown in Fig. 5. The campus three-dimensional data visualization model based on the ContextCapture platform can not only provide unique data and three-dimensional space interaction, but also provide more realistic visualization effects in multiple dimensions. Moreover, it can be connected to real-time data, and various types of data that cannot be accommodated or expressed in static displays, such as text, numbers, and charts, as well as traditional interfaces and single data, can be placed in the three-dimensional model for presentation. Various logic buttons and status animations are used to give users the experience of interacting with real-time data. This makes the data more three-dimensional and gives the dull and single data flexible and diverse visual effects. The overall framework of the visualization platform is shown in Fig. 5.

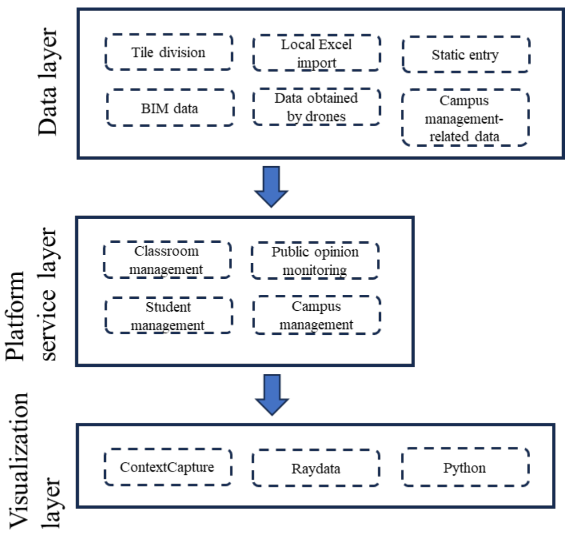

Fig. 5. Overall framework structure diagram of the visualization platform

The platform architecture is shown in the figure. Under the premise of adhering to the standard specification system and information security system, this platform is composed of a visualization layer, a platform service layer, and a data layer, which can achieve high-quality campus scene simulation and visualization effects. This architecture ensures the platform's high flexibility, stability, and scalability, providing rich interactive experiences and efficient data analysis functions.

The osgb format file is obtained through the 3D model construction by drone oblique photography and ContextCapture. Further, the data is transformed into 3D Tiles data that can be recognized and loaded by Cesium, with the data format being json and related tile data packages. Cesium is used for model rendering, and the Browser/Server (B/S) architecture is adopted. Visitors can access the 3D real scene model of the campus through the browser. Considering the complexity of the 3D model, the rendering efficiency is of vital importance [22].

Data import includes multiple access methods such as online data access, local Excel import, and static entry. The access method can be selected according to needs. For example, textual descriptions such as college and major introductions can be entered statically. After selecting the database type, enter the database connection string and prepare the SQL statement for querying data. Ensure the accuracy of the connection string and SQL statement to complete data reading. When accessing online data, create a node, select the data mode as Web data, and Web data supports two submission methods: get and post. The get method can be used, and the target URL is entered in the URL. After reading the data using the interface URL, the read data can be seen in the output properties. The layout and node size can also be adjusted, and data processing can be carried out through logical nodes. Local Excel import is relatively simple, and the basic steps are the same as online data access. It is necessary to pay attention to placing the Excel file in the corresponding folder and entering the table name to successfully read the data.

The design process of some pseudo-code:

```
# Pseudocode: Data Collection
def collect_data():
    # Collect campus data from sensors, databases, APIs, etc.
    sensor_data = read_sensors()  # Read sensor data
    db_data = query_database()    # Query the database
    api_data = fetch_api_data()   # Fetch data from an API
    # Return the collected data
    return sensor_data, db_data, api_data
# Pseudocode: Data Processing
def process_data(sensor_data, db_data, api_data):
    # Data cleaning
    cleaned_sensor_data = clean_data(sensor_data)
    cleaned_db_data = clean_data(db_data)
    cleaned_api_data = clean_data(api_data)
    # Data integration
    combined_data = combine_data(cleaned_sensor_data, cleaned_db_data, cleaned_
api_data)
    # Data transformation
    transformed_data = transform_data(combined_data)
    # Return the processed data
    return transformed_data
# Pseudocode: Modeling
def build_model(processed_data):
    # Choose a modeling method (e.g., 3D modeling, GIS modeling)
    model = create_3d_model(processed_data)  # Create a 3D model
    # Model optimization
    optimized_model = optimize_model(model)
    # Return the model
    return optimized_model
# Pseudocode: Data Visualization
def visualize_data(model, processed_data):
    # Choose a visualization tool (e.g., Matplotlib, Tableau, WebGL)
    visualization_tool = select_visualization_tool()
   # Create visualization
    visualization = create_visualization(model, processed_data, visualization_
tool)
```

```
    # Display visualization
    display_visualization(visualization)
# Pseudocode: Main Workflow
def main():
    # Data collection
    sensor_data, db_data, api_data = collect_data()
    # Data processing
    processed_data = process_data(sensor_data, db_data, api_data)
    # Modeling
    model = build_model(processed_data)
    # Data visualization
    visualize_data(model, processed_data)
# Execute the main workflow
main()
```

4.3 Digital Twin Urban Management Method Based on BIM

Oblique photogrammetry technology is mainly used to obtain high-precision data on the external structure of buildings. For the collection and management of internal building information, BIM technology can be employed to deeply integrate building information with comprehensive urban management information. BIM technology covers the entire life cycle data of a construction project, from design, construction to operation and maintenance, including but not limited to structural types, building materials, and construction progress. Additionally, by integrating multi-source data at the campus level (such as student information, public facility status, security surveillance records, etc.), BIM technology can build a comprehensive information platform with full functionality. This platform not only enables smart city managers to grasp the status of buildings and their surrounding environment in real time, but also provides convenient query functions that can quickly locate the position, specifications, and maintenance records of various facilities within buildings, and track students' activity trajectories and service demands, laying a solid technical foundation for refined management and personalized services. Moreover, with the data correlation and dynamic update capabilities of BIM technology, building information and campus information can be efficiently synchronized, effectively solving the common problems of information silos and data lag in traditional management models, and significantly improving the management efficiency and decision-making accuracy of smart cities. It is worth noting that as a microcosm of the city, the digital transformation of the campus can not only be achieved by expanding the functional modules of the digital campus, but also by interconnecting with external information such as transportation and communities around the campus, gradually building a complete digital twin city system [23].

In the daily management of digital twin cities, equipment maintenance is a key link. Through the three-dimensional positioning function of BIM technology, managers can accurately locate target equipment and quickly access detailed information, thereby significantly shortening the time cycle for troubleshooting and repair. In the field of emergency management, BIM technology combined with GIS and Internet of Things (IoT) technology can simulate in real time the evacuation routes and rescue plans in emergency situations such as fires and earthquakes, providing strong technical support for urban safety. In addition, BIM technology can be deeply integrated with IoT technology to monitor the operating status and performance parameters of equipment in real time. Once equipment malfunctions or fails, the system will automatically trigger a warning mechanism and send maintenance notifications to relevant personnel, greatly reducing the response time to faults and improving emergency handling efficiency.

Meanwhile, with the help of the 3D visualization function of BIM technology, energy consumption data can be presented in a more intuitive and understandable way, assisting smart city managers in quickly identifying high-energy consumption areas and periods, and then formulating targeted energy-saving strategies. For instance, in the heating system, BIM technology can simulate the changes in energy consumption under different temperature setting conditions to help managers determine the optimal heating temperature setting, thereby achieving efficient energy utilization and precise management [24].

5 Feasibility Analysis

By using the method in Section Three, the data collected by the unmanned aerial vehicle was used for 3D modeling. During the model processing, the five-direction flight data and the air-ground fusion data were processed separately. The texture fineness of the model results was compared and examined. The building was surveyed by oblique photogrammetry using the air-ground fusion method. To verify the accuracy of the data collected by the oblique measurement in this paper, there were three field measurement check points in the study area. The measurement function provided by the ContextCapture platform Acute3D Viewer was used to measure the check points multiple times in the generated 3D model, and the average value was taken as the coordinate of the check point. The statistics of the measured values corresponding to the model check points are shown in Table 3.

Table 3. Checkpoint corresponding coordinates

Checkpoint name	Three-dimensional error(m)	Horizontal error(m)	Height error(m)
A_1	0.00301	0.00151	-0.00093
A_2	0.00221	0.00243	-0.00136
A_3	0.00297	0.00197	0.00105

From the above results, it can be seen that the errors of the three control points meet the requirements of the "Specification for 3D Geographic Information Model Data Products" (CH/T 9015 2012), which stipulates that the planar accuracy of the 3D model at level I should be less than 0.3 meters and the height accuracy should be less than 0.5 meters.

To ensure the efficiency of 3D graphics rendering and the normal development and operation of the system, the computer's software and hardware configuration should not be lower than the minimum configuration of the WebGL graphics processing environment. The software and hardware development environment configuration of this system is shown in Table 4.

Table 4. Computer hardware configuration parameters

Configuration name	Configuration parameters
CPU	Core-i7
Operating system	Windows 11
GPU	NVIDIA RTX 4070
Memory	32GB
Editor	VS
Web browser	Chrome
Software support environment	Node.js

6 Conclusion

Oblique photography is widely used in the construction of large-scale urban real-scene models. The generated 3D real-scene models highly restore the real scenes. However, due to its technical characteristics, the digital surface models (DSMs) generated by oblique photography are limited to outdoor scenes of buildings. BIM, based on 3D digital technology, provides a detailed 3D spatial expression of all objects inside buildings, making up for the deficiency of oblique photography that only covers outdoor scenes and highly integrates various attributes and engineering information of building components. Meanwhile, in the aspect of multi-source 3D model data visualization, with the integration of Internet technology and GIS technology, the emergence of HTML5 standards and WebGL, the realization of 3D geographic information visualization based on WebGL has become a new method.

This paper conducts research on the visualization of indoor and outdoor integrated scene modeling based on oblique photogrammetry and BIM technology, taking the digital campus as the object, and provides a complete method from data acquisition to the construction of a full-space 3D digital model. However, there are still many problems that need further research.

1) How to efficiently extend the method proposed in this paper to digital cities to provide efficient technical services for urban construction and planning and improve urban management levels is the most important direction for in-depth research in this paper.

2) In the aspect of oblique photogrammetry, the 3D models constructed are essentially point cloud and texture data, and the generated 3D meshes are an integral whole. The automatic segmentation of DSMs and the completion of automatic individualization still need to be studied.

3) The application of BIM technology in this paper is only at the BIM design stage, and the integration and application of BIM with oblique true 3D models in the construction, operation, reconstruction, and demolition stages have not been studied. This will be further improved in future work.

4) It is rather difficult to select from all the oblique images those that can fully reflect the characteristics of all the building facades in the survey area. If the number of photos is too small, it will be impossible to extract all the vertical lines. If the number of photos is too large, it will lead to the repeated extraction of the same vertical line of a building facade in different images, reducing the calculation efficiency. Therefore, in the subsequent research, the photo selection process needs to be optimized to ensure the image coverage while avoiding the waste of computing power.

5) For large-scale 3D models, the construction time is relatively long. Therefore, the 3D model needs to be divided into blocks. In the subsequent work, the segmentation algorithm combined with artificial intelligence should be explored for optimization to improve the construction efficiency of large-scale 3D models.

6) Oblique images are the most fundamental data source for extracting building corner points. However, due to the low photo resolution and the insignificant pixel gradient difference in some concave corner areas of buildings, they are not easily detected in the building line extraction algorithm. Therefore, in the subsequent research, the extraction of concave corner points of buildings should be further studied.

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