BIM-Based Rapid Generation of High-Precision 3D Models: Method Research and Application Exploration (Postprint)

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Date: 2018-10-26T00:00:00+00:00

Abstract

Reality modeling; oblique photogrammetry; full lifecycle; tunnel inspection

Full Text

Research on Rapid Generation of High-Precision 3D Models Based on BIM and Its Application Exploration

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Abstract

The development of Building Information Modeling (BIM) technology has catalyzed a new revolution in the construction industry. As concepts of green building, intelligent architecture, and urban sustainable development continue to deepen, existing modeling methods can no longer meet the demands of modern modeling requirements. In recent years, three-dimensional real-scene modeling technology has been widely applied for reconstructing models of existing buildings, yet technicians face the critical challenge of achieving high-precision, rapid, and cost-effective real-scene models. This paper employs oblique photogrammetry technology to realize three-dimensional real-scene modeling, proposes an implementable reference solution based on actual engineering cases, and introduces a method for monitoring tunnel portal settlement using real-scene modeling.

Keywords: real-scene modeling; oblique photogrammetry; life cycle; tunnel detection

1. Limitations of Traditional Real-Scene Modeling Methods

Currently, three primary modeling approaches exist: (1) manual creation of two-dimensional building models using various drafting software based on design concepts; (2) extraction of three-dimensional point cloud data from object surfaces using 3D laser scanning technology to form measured object models; and (3) acquisition of multi-angle image data of buildings through oblique photogrammetry, followed by office processing to generate three-dimensional real-scene models. Among these, manual modeling consumes substantial human resources and time for model reconstruction, often resulting in accuracy that merely matches the drawings rather than the actual structure, with significant deviations from real buildings and notably low efficiency. While laser scanning technology can achieve high-precision and rapid model generation, the equipment is typically imported and expensive, making it impractical for small-scale projects to purchase. In contrast, using unmanned aerial vehicles (UAVs) equipped with cameras for oblique photogrammetry represents the optimal current method for achieving high-precision, rapid, and low-cost three-dimensional real-scene modeling.

For existing structures, modeling based on drawings cannot reflect real-time conditions. Over time, buildings may experience slight settlement or deformation due to long-term loading. Manual modeling cannot directly capture building textures, requiring post-processing texture acquisition and application. Most buildings are situated in urban areas with dense vegetation and busy streets, where excessive occlusions prevent 3D laser scanning from comprehensively capturing complete surface data. Bridges and tunnels, typically located in suburban or geologically poor areas, or at urban transportation junctions, present significantly increased modeling challenges due to harsh geological conditions or complex traffic situations. Tunnels are often situated in mountains or underground, where portal models are critically important. Portal displacement and settlement monitoring holds paramount importance during both construction and subsequent maintenance periods. These challenges necessitate a feasible solution. We can now employ UAV-mounted cameras for oblique photography of buildings, supplemented by manual camera work in inaccessible areas, substantially reducing labor, material, and financial requirements.

2. Real-Scene Modeling Using Oblique Photogrammetry

Real-scene modeling technology creates models from photographs, videos, and point cloud data. For real-scene modeling systems, data acquisition, correction and fusion, processing and modeling, and subsequent model utilization are all essential components. Compared with traditional modeling methods, real-scene modeling technology offers more promising long-term applications, primarily manifested in high efficiency across three dimensions: data acquisition efficiency, data analysis efficiency, and mechanized modeling efficiency. Leveraging UAVs equipped with intelligent cameras, real-scene modeling technology enables fine-grained collection and transmission of real-time site data. Traditional data collection involves surveyors acquiring data for clients, who then pass it to contractors, during which data may already become outdated. In contrast, real-scene modeling data collection offers greater timeliness. Predominantly employing mechanical tools, this technology significantly reduces unnecessary manual labor while achieving data collection speeds unattainable by human effort. The final result presents a virtual three-dimensional world that mirrors the real world—when real-world lighting changes, virtual lighting changes accordingly. All data, dimensions, and information can be directly extracted, queried, and modified within the model, greatly facilitating data processing and storage. The integrated model comprising real-scene and digital components features geolocation capabilities, while the efficient modeling approach substantially shortens design cycles.

Oblique photogrammetry is a rapidly developing high-tech method that has matured over recent decades. By simultaneously collecting image data from different angles, it creates data that appears to enter a truly intuitive world from a human perspective. Using oblique photogrammetry, relevant software can directly display measurements for height, length, area, angle, slope, and other parameters while extracting ground spatial positions, building structures, colors, and textures—making it a crucial technology for implementing three-dimensional real-scene modeling [1].

Combining UAVs with oblique photogrammetry represents an effective method for low-cost, rapid establishment of three-dimensional urban real-scene models. Due to low flight altitudes, UAVs capture high-resolution oblique images with colors closer to human observation, significantly enhancing the realism of urban 3D models. This project employs the DJI Phantom 4 UAV aerial platform [Figure 1: see original paper] with primary parameters shown in Table 1.

Table 1: UAV Basic Parameters

Parameter	Value
Aircraft Type	Quadcopter
Application	Professional cinematography and commercial aerial photography
Max Ascent Speed	6 m/s
Max Descent Speed	4 m/s
Max Flight Speed	20 m/s
Max Service Ceiling	6000 m
Diagonal Wheelbase	350 mm
Photo Resolution	4000 × 3000
Controllable Rotation Range	Pitch: -90° to +30°
Reference Market Price	6999 RMB

3. Technical Workflow for Problem Solving

The implementation process comprises five key stages. First, preparation and site investigation involve communicating with building management to understand historical development, conducting preliminary site surveys, identifying surrounding structures, determining optimal takeoff locations, and locating facilities for equipment charging. Second, flight parameters must be established by selecting appropriate flight platforms and designing suitable routes and timing. Different scenarios require different photographic emphases, necessitating preliminary test flights to ensure optimal model presentation. Two primary flight patterns are employed: (a) circular envelope routes centered on the building’ s base midpoint, where the UAV orbits at constant speed and angle [Figure 2: see original paper]; or (b) rectangular boundary routes with repeated linear flights above the building [Figure 3: see original paper]. Circular routes enable multi-angle shooting with fewer blind spots, suitable for small-scale single buildings, while linear routes provide macro-level coverage of all structures, vehicles, and vegetation within the designated area, ideal for large-scale scenes [2].

Third, data acquisition follows the prepared flight plan for each building. Due to site-specific geographical features, UAV shooting may encounter blind spots requiring manual camera supplementation to capture details in inaccessible areas. These datasets are then fused into a complete building model. During acquisition, insufficient image overlap results in poor data processing quality and model holes, while excessive overlap creates unnecessary data redundancy. Therefore, image overlap is typically controlled at approximately 80%. Fourth, data processing employs Context Capture software to generate three-dimensional real-scene models, with subsequent modifications performed in MicroStation. Context Capture provides models with precise geolocation information and supports multiple data formats for both input and output. The workflow involves creating a new project, importing collected photos and point cloud data, reviewing photo information and capture methods, performing Structure from Motion (SfM) aerotriangulation to calculate camera positions and generate dense point clouds through image dense matching, partitioning tasks after obtaining 3D TIN data, and finally submitting computation tasks for texture mapping. Upon completion, the system prompts users to click 3D View to examine the generated model. Fifth, the generated models can be saved in various formats for import into different software platforms to support landscape design, animation display, construction simulation, and monitoring/detection across the entire project life cycle.

4. BIM Applications in Real Projects

4.1 Ancient Building Restoration Confucian temples, serving as halls for worshipping Confucius, constitute an extremely important component of China’ s ancient cultural heritage, preserving the past and future of Chinese culture. Chenggong Confucian Temple, located on Chenggong’ s East Gate Street, features a south-to-north central axis layout with existing structures including the

Pan Pool, Lingxing Gate, east and west corridors, and Dacheng Hall, covering 8.34 acres. Having experienced multiple destructions and renovations over its 600-year history, it represents the earliest existing Confucian temple structure in the Kunming region. After the founding of the People' s Republic of China, it served as government office space before falling into disrepair through long-term vacancy. Now designated as a municipal cultural relic protection unit requiring restoration to its original state, our modeling work captures the partially restored original condition to support overall planning and design.

For this project, we employed the DJI Phantom 4 UAV for oblique photogrammetry of the Chenggong Confucian Temple in Kunming, Yunnan Province, at flight altitudes of 6–10 meters with longitudinal and lateral overlaps exceeding 75%. For protruding or hollow architectural elements, local multi-angle re-acquisition was necessary. The primary challenge involved the temple' s location within a bustling residential area surrounded by tall trees and buildings, restricting UAV operations. Given ancient architecture' s finer details compared to modern structures, we adopted a grouped shooting approach for the main components: overall site, Pan Pool, Confucius statue, Lingxing Gate, and Dacheng Hall, generating separate models. Linear flight routes captured the overall scene, followed by individual component extraction [3]. For higher precision, circular flight routes were used for the four main structures. Since building eaves created unavoidable blind spots and dense temple trees prevented UAV flights, manual camera supplementation captured these areas, with integrated data generating the final model [Figure 4: see original paper].

Figure 4: Distribution of Image Control Points

Context Capture-generated models may include unnecessary elements, requiring import into MicroStation for clipping unwanted portions and combining the five shooting groups into an integrated model [Figure 5: see original paper].

Figure 5: Schematic of Local Model Assembly

LumenRT, known as "site simulation software," creates realistic scenes for digital infrastructure information models. The final integrated model was imported into LumenRT to faithfully reproduce the existing temple environment and support landscape planning, transforming the temple into a cultural and recreational tourism destination. The overall road layout follows a Bagua (Eight Trigrams) pattern centered on the Pan Pool, Confucius statue, Lingxing Gate, and Dacheng Hall, with a parking area (separating motor vehicles and non-motorized vehicles) on the east side and a rest center with cultural exchange corridors and seating on the west side. To preserve the temple environment, the rest area does not provide dining services [FIGURE:6-7].

Figure 6: Overall Model Effect Schematic
Figure 7: 3D Real-Scene Model of Confucius Statue and Lingxing Gate

4.2 Tunnel Portal Monitoring and Detection With rapid infrastructure development, increasing numbers of mountain tunnels have emerged for highways and railways. Mountain tunnel geological conditions are typically complex and variable, particularly at portal sections where surrounding rock is often fractured with poor geological conditions, and excavation of slopes destroys original mountain equilibrium. Consequently, portal sections represent extremely complex geological zones where detection and maintenance are paramount. Portal monitoring typically includes surface monitoring (using levels to observe surface settlement and cracks) and internal monitoring (crown settlement, peripheral displacement, and geological/support condition observation). Traditional methods rely on manual detection, but tunnels are often located in remote mountainous areas or complex terrain with significant limitations. Considering the special challenges, difficulties, complexity, and substantial resource consumption of tunnel monitoring, this paper proposes combining real-scene modeling with dynamic testing technology for portal displacement and settlement monitoring, enabling rapid 3D portal model establishment without extensive labor or machinery costs, with models imported into monitoring platforms for real-time observation.

The experiment utilized the UAV aerial equipment shown in [Figure 8: see original paper], featuring a camera lens with FOV 94°, 35mm f/2.8 focal length at infinity, a 1/2.3-inch CMOS sensor, and 12.76 million effective pixels. The test subject was the Tigupu Tunnel on the Chenggong-Chengjiang section in Yunnan Province—a typical mountain tunnel with six bidirectional lanes, with its entrance at a mountain foot and exit on a mountainside, measuring 1,730m and 1,684m for left and right separate tunnels.

Following oblique photogrammetry methods, the UAV flew at 18 meters altitude with 0.8 longitudinal and lateral overlap, capturing 75 images along a single route [Figure 8: see original paper]. Using the aforementioned data processing methods, the captured images were processed to generate dense point clouds, 3D TIN, and real-scene models. The generated 3D real-scene model was integrated with BIM models and imported as a 实景网格 (real-scene mesh) into OpenRoads to combine with generated tunnel structures, then processed in InRoads Suite to incorporate survey information—handling any type of field data including surveys, ASCII, GPS, LiDAR, contour maps, photogrammetry, and various other formats. Data can be modified and processed as needed, and after design completion, uploaded to data collectors for monitoring or to automatic machine guidance devices for field implementation.

Since the acquired image data inherently contains precise geolocation information (or can be imported into Context Capture if absent), the final 3D models contain positional data for both input and output. Repeated periodic image data acquisition can be performed for the same tunnel portal, with models imported into monitoring software for deformation analysis. Any displacement deviation will manifest as deviation between periodically generated models and the original model, preventing perfect alignment with the tunnel structure. Multiple data collections during the same period help avoid errors from human or mechanical factors, with outlier data showing larger deviations being eliminated. Regular data collection enables establishing several control points on models and plotting deformation process curves for each point' s directional deformation values, intuitively reflecting deformation trends, patterns, and magnitudes [Figure 8: see original paper].

Figure 8: Tunnel Portal Deformation Analysis

Regular, repeated image data collection for tunnel portals using UAVs enables office-based real-scene model establishment, with models integrated into cloud platform technology for real-time data transmission and periodic data organization. Leveraging rapid computer technology development, an integrated monitoring system encompassing data collection, organization, analysis, reporting, and feedback can be established, enabling real-time digital information acquisition and implementation data management. Cloud platforms facilitate rapid data transmission and ensure all project participants can upload and download data. Typical monitoring systems include sensor subsystems, data acquisition and transmission subsystems, and data management subsystems. The BIM concept establishes a virtual world parallel to reality, using sensors installed at tunnel portal components during initial construction to collect real-time data transmitted to cloud platforms for analysis. Through computational analysis, real-time reflection of mechanical performance, structural characteristics, and temporal variations enables true BIM implementation throughout the entire project life cycle [4] [FIGURE:9-13].

Figure 9: Aerial Triangulation Results
Figure 10: Task Area Division
Figure 11: Tunnel Entrance Model
Figure 12: Tunnel Exit Model
Figure 13: Integration of Real-Scene Model with Tunnel Portal

4.3 Technical Limitations Oblique photogrammetry captures true object heights, and comparison between actual measurements and constructed models shows errors can be controlled at the millimeter level, making models suitable for planning references .

Table 2: Comparison Between Actual Measurement Data and 3D Model Measurement Data (Units: m)

Measurement	Actual Value	3D Model Value
Depth	1.60	1.62

For refined management of individual buildings, oblique photogrammetry first acquires large-scene data, followed by office processing that enables individual building extraction from the generated 3D real-scene model. The 3D real-scene data is converted to .3ds or .obj format and imported into 3ds Max to extract and split required individual buildings from the large scene, which are then named according to conventions and exported as .max format individual element objects [FIGURE:14-15].

Figure 14: Complete 3D Real-Scene View
Figure 15: Individual Object Extraction

During data acquisition, insufficient image data, low-resolution imagery, planar surfaces lacking texture or color variation, or high-reflection phenomena from lighting can "blind" cameras, resulting in inaccurate surface information and "hole" defects in generated 3D real-scene models. Oblique photogrammetry can perform "hole-filling" through manual constraint addition for planar processing of designated areas, achieving perfect 3D and 2D GIS integration while preserving model quality, original data, and LOD. This not only compensates for inherent oblique photogrammetry data issues but also improves irregular object reconstruction accuracy. The Lingxing Gate model shows hole defects in the characters area [Figure 15: see original paper], with repaired results shown in [Figure 16: see original paper].

Figure 16: Repaired Real-Scene Model (After MS Patching)

As demonstrated in the two case studies, oblique photogrammetry currently faces shooting blind spots such as building eaves, tunnel portal interiors, and underpasses. UAV lenses function like human eyes, unable to see behind occlusions, making these areas unavoidable blind zones. Current solutions combine manual data acquisition with UAV collection. The integration of oblique photogrammetry with street view can leverage existing resources while compensating for both technologies' limitations, though specific implementation depends on project requirements.

Real-scene modeling technology has become an industry-recommended approach. UAV-mounted camera oblique photogrammetry enables rapid, low-cost, high-precision 3D real-scene model construction. This technology can integrate with numerous practical engineering applications, substantially reducing project costs, improving efficiency, and accelerating progress. Real-scene modeling technology will undoubtedly drive the development of digital cities and digital Earth initiatives.

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