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Research and Implementation of a 3D Digital Surveying and Mapping Scheme for Building Facades

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Abstract: This paper focuses on the 3D digital surveying and mapping scheme for building facades. It analyzes the principles, advantages, and limitations of key technologies, including laser scanning, photogrammetry, and 3D modeling, and elaborates on the necessity of technology integration and appropriate hardware–software selection. The study introduces methods for multi-source data collaborative acquisition and preprocessing, 3D model reconstruction and optimization, as well as BIM-based integration and application of results. Through multi-source data collaboration and technological integration, high-precision surveying and mapping of building facades can be achieved. The results can be applied to various scenarios such as building operation and maintenance, renovation, and refurbishment, thereby expanding the application value of 3D surveying and mapping outcomes.

Keywords: 3D digital surveying and mapping; LiDAR; UAV oblique photogrammetry

Introduction

Three-dimensional (3D) digital surveying and mapping of building facades is of great significance for architectural planning, operation and maintenance, and renovation. With the advancement of technology, the limitations of single surveying methods have become increasingly apparent, making it difficult to meet the demands of complex scenarios. Laser scanning offers high precision but relatively low efficiency, whereas photogrammetry provides high efficiency but is sensitive to occlusions. Consequently, technological integration and multi-source data collaboration have become an inevitable trend. This paper aims to investigate a 3D digital surveying and mapping scheme for building facades by analyzing the principles and selection of relevant technologies. It further introduces methods for data acquisition and processing, model reconstruction and optimization, and BIM-based application of results, thereby providing practical references for related engineering applications.

1. Principles and Selection of 3D Surveying Technologies for Building Facades

1.1 Analysis of Key Technologies

The core of 3D surveying and mapping of building facades lies in capturing spatial coordinates, geometric configurations, and texture information, and converting them into quantifiable and editable three-dimensional data, thereby laying the foundation for subsequent model reconstruction and application. At present, the mainstream key technologies include laser scanning, photogrammetry, and 3D modeling technologies.

Laser scanning technology is based on the principle of laser ranging. By emitting laser pulses, it acquires high-precision point cloud data and can accurately capture surface geometric details of building facades. It is particularly suitable for buildings with complex forms. Photogrammetry technology is grounded in the principle of binocular vision. By capturing images from multiple angles and extracting spatial information, it provides an efficient and cost-effective solution, especially suitable for large-area surveying tasks. Three-dimensional modeling technology integrates the collected point cloud and image data to establish a 3D model, and employs algorithmic optimization to ensure consistency between the model and the actual building. Each technology has its own advantages and limitations; therefore, a rational combination should be determined in accordance with specific project requirements.

1.2 Necessity of Technology Integration

Surveying scenarios for building facades are often complex, and the limitations of a single technology are evident. Technology integration has become an inevitable approach to improving surveying efficiency, accuracy, and applicability. When used independently, laser scanning demonstrates relatively low efficiency in large-area surveying, has limited capability in capturing texture information, and may generate redundant data. Conversely, standalone photogrammetry is prone to data loss and insufficient accuracy in areas with severe occlusion or complex geometries, making it difficult to meet refined surveying requirements [1]. Moreover, different projects impose varying requirements on surveying outcomes, which a single technology often cannot simultaneously satisfy. By integrating laser scanning and photogrammetry, their respective advantages can complement each other. Laser scanning compensates for the accuracy limitations of photogrammetry, while photogrammetry enhances the efficiency of laser scanning and improves texture acquisition capabilities. When combined with 3D modeling technologies for further optimization, this integrated approach effectively addresses surveying challenges in complex scenarios and establishes a solid foundation for subsequent applications.

1.3 Hardware and Software Selection

Reasonable selection of hardware and software is crucial to ensuring the smooth implementation of 3D surveying and mapping of building facades and improving the quality of results. Comprehensive consideration should be given to project scale, accuracy requirements, site conditions, and budget constraints. In terms of hardware selection, high-precision and high-resolution terrestrial 3D laser scanners are preferred for laser scanning equipment, balancing scanning speed and operational convenience. For elevated or hard-to-access areas, UAV-mounted LiDAR systems can be employed. For photogrammetry, full-frame DSLR cameras or UAV aerial survey cameras should be selected to ensure image clarity and resolution sufficient for reliable feature point extraction. For data storage, large-capacity and high read–write speed mobile hard drives or servers are recommended to ensure secure storage of massive point cloud and image datasets. Regarding software selection, point cloud processing software such as Cyclone and CloudCompare can be used for point cloud registration, denoising, and segmentation. Image processing software such as Pix4Dmapper and PhotoScan can be employed for image matching and aerial triangulation. For 3D modeling, software such as ContextCapture and DJI Terra can be utilized to reconstruct models based on facade characteristics. Additionally, BIM-related software such as Revit, SketchUp, and 3ds Max can support subsequent model refinement and application. Domestic software such as DP Modeler may be used for post-model editing, while production applications can adopt CASS11 or Southma 4.0 developed by Southern Surveying & Mapping. Overall, the selection of hardware and software should adhere to the principles of practicality, compatibility, and cost-effectiveness.

2. Multi-Source Data Collaborative Acquisition and Preprocessing Scheme

2.1 Design of Data Acquisition Strategy

The core of a multi-source data collaborative acquisition strategy lies in integrating various data acquisition methods—such as laser scanning and photogrammetry—around the specific requirements of building facade surveying, and formulating a scientific and well-structured acquisition workflow to ensure data completeness, consistency, and high precision.

First, a site investigation should be conducted to clarify the building's scale, architectural form, surrounding environment, and occlusion conditions. Based on this assessment, acquisition areas and routes are delineated to avoid data blind spots. For easily accessible areas such as the lower and middle sections of the building, terrestrial 3D laser scanners are employed for close-range, high-precision scanning. Appropriate scanning resolution and spacing should be configured to ensure that detailed facade features are accurately captured. For high-altitude areas, rooftops, and other inaccessible sections, a combination of UAV-mounted LiDAR and aerial photogrammetry is adopted. UAV flight routes should be carefully planned, with controlled flight altitude, speed, and image overlap to guarantee the continuity of image and point cloud data [2]. Simultaneously, texture images of the building facade should be acquired to ensure accurate correspondence between texture and geometric data. During the acquisition process, data quality must be inspected in real time. Blurred, missing, or low-accuracy data should be promptly re-collected. A multi-source data acquisition log should be established to record acquisition time, location, equipment parameters, and other relevant information, thereby ensuring data traceability and providing reliable support for subsequent preprocessing and model reconstruction.

2.2 Data Preprocessing Workflow

After completing multi-source data acquisition, a systematic preprocessing workflow is required to eliminate errors, integrate heterogeneous data resources, and transform raw data into standardized datasets suitable for model reconstruction. This stage is critical to ensuring the quality of 3D surveying and mapping results. The preprocessing workflow mainly includes data organization, denoising, stitching, registration, and standardization. First, the collected raw data—such as point clouds and images—are organized and classified. Invalid and redundant data are removed, and data completeness is verified. For point cloud data, filtering algorithms are applied to remove environmental noise and spurious points caused by equipment errors, retaining only the valid point cloud representing the building facade. Point cloud simplification is then performed to improve processing efficiency without compromising accuracy. For image data, distortion correction, exposure adjustment, and image enhancement are conducted to improve clarity and provide a solid foundation for subsequent feature extraction. Subsequently, multi-source data stitching and registration are carried out. Through coordinate transformation algorithms, data acquired from different devices and regions are unified into a common coordinate system to ensure spatial consistency. Finally, the preprocessed point cloud and image data are standardized and converted into unified formats, facilitating subsequent processes such as point cloud segmentation, feature extraction, and 3D model reconstruction.

3. 3D Model Reconstruction and Optimization of Building Facades

3.1 Point Cloud Segmentation and Feature Extraction

Point cloud segmentation and feature extraction constitute the fundamental prerequisites for 3D model reconstruction of building facades. The objective is to isolate the effective regions of the building facade from massive preprocessed point cloud datasets and to extract key geometric and texture features, thereby providing accurate data support for model reconstruction. Point cloud segmentation is typically conducted using geometry-based segmentation algorithms. Combined with the structural characteristics of building facades, point cloud data are classified and segmented into different components such as walls, doors and windows, cornices, and columns. Irrelevant point clouds—such as ground surfaces, vegetation, and surrounding buildings—are removed to clearly define the spatial positions and boundary extents of each component. During the segmentation process, algorithm parameters are carefully adjusted to ensure boundary accuracy and to prevent issues such as component misclassification or incomplete segmentation. Feature extraction is performed on the segmented point clouds of individual components to obtain key feature parameters. These include geometric features such as planes, straight lines, and curves, as well as texture features such as grayscale values and texture orientation. Through feature extraction, the dimensions, shapes, and spatial relationships of facade components can be determined, including planar parameters of walls, positions and dimensions of doors and windows, and heights and cross-sectional shapes of columns. This process provides reliable data for precise

3D model reconstruction, reduces modeling workload, and improves reconstruction efficiency.

3.2 Methods for 3D Model Reconstruction

The reconstruction of 3D models of building facades requires the integration of preprocessed point cloud and image data, along with the adoption of appropriate reconstruction methods to ensure accuracy, completeness, and fidelity to the actual architectural form. Currently, mainstream reconstruction approaches include point cloud-based methods and image-based methods. By leveraging the advantages of multi-source data collaboration, a fusion-based reconstruction approach can further enhance model quality. Point cloud-based reconstruction methods transform discrete segmented point cloud data into continuous 3D surfaces through surface fitting and mesh generation techniques. Combined with extracted component feature parameters, a 3D model of the building facade is constructed. This method offers high geometric accuracy and can precisely restore architectural forms, making it particularly suitable for reconstructing components with complex geometries [3]. Image-based reconstruction methods utilize image matching algorithms to extract feature points from images and generate 3D point clouds. Texture mapping techniques are then applied to project facade texture images onto the surface of the 3D model, thereby producing realistic visual effects. This method is especially suitable for reconstructing large-scale building facades with rich texture details.

3.3 Model Optimization and Lightweight Processing

After the completion of 3D model reconstruction, optimization and lightweight processing are required to eliminate modeling errors and simplify structural complexity. The objective is to ensure that the model meets accuracy requirements while maintaining practicality and operability, thereby facilitating subsequent integration and application. Model optimization primarily addresses errors and defects generated during the reconstruction process, including geometric error correction and texture enhancement. Geometric error correction involves comparing the reconstructed model with actual surveying data and design drawings to adjust dimensions, positions, and morphological features, thereby eliminating issues such as uneven surfaces and component misalignment. Texture optimization focuses on refining surface textures by correcting blurring, stretching, and misalignment, improving clarity and consistency to ensure closer conformity with the building's actual appearance. Model lightweight processing aims to resolve problems such as large data volume, excessive storage requirements, and performance lag during operation. Model simplification algorithms are applied to remove redundant meshes and unnecessary data while preserving accuracy and key structural features, thereby reducing overall model complexity. In addition, hierarchical structuring and component-based segmentation of the model are performed to facilitate subsequent editing, visualization, and application. This ensures smooth import into BIM software for integration, compatibility with diverse application scenarios, and enhanced practicality and scalability of 3D surveying results.

4. BIM-Based Integration and Application of 3D Surveying Results

4.1 BIM Model Construction and Data Integration

The core of BIM-based integration of 3D surveying results lies in the deep integration of the optimized 3D facade model with BIM technology to establish a standardized BIM model and achieve unified fusion of multi-source surveying data. This approach leverages the visualization and informatization advantages of BIM technology. First, based on the optimized 3D model, supplementary information from architectural design drawings, construction documents, and related materials is incorporated to enrich the attribute data of facade components. These attributes include material properties, dimensions, specifications, and construction timelines. In this way, a comprehensive BIM model of the building facade is established, ensuring that the model contains not only geometric representations but also detailed semantic and attribute information. Subsequently, multi-source data integration is performed. Laser scanning point clouds, photogrammetric images, preprocessed datasets, and relevant design, construction, and operation and maintenance (O&M) data are systematically integrated into the BIM model. Through data association algorithms, interoperability among different data types is achieved. During the integration process, data consistency and accuracy are strictly maintained, and redundancy and errors are eliminated. As a result, the BIM model serves as the core carrier for consolidating surveying results and architectural information, enabling digitalized and information-based management of 3D surveying outcomes for building facades and providing robust data support for the expansion of subsequent application scenarios.

4.2 Expansion of Application Scenarios

The BIM-based 3D surveying results of building facades, characterized by high precision, visualization, and informatization, can be widely applied in various scenarios such as building O&M, renovation and refurbishment, emergency management, and urban renewal, thereby expanding the application value of 3D surveying outcomes. In terms of building O&M, relying on the attribute information and three-dimensional geometry embedded in the BIM model enables refined management of facade components. This includes aging detection of components, formulation of maintenance plans, and identification of potential safety hazards, thereby improving operational efficiency and safety performance [4]. For renovation and refurbishment projects, the BIM model allows precise acquisition of dimensional, morphological, and structural information of building facades, providing accurate references for renovation scheme design and construction simulation. This approach helps to avoid rework and material waste during the renovation process, effectively reducing project costs. In the field of emergency management, leveraging the visualization capabilities of the BIM model facilitates rapid identification of hazardous areas on building facades and supports the development of targeted emergency response plans, thereby enhancing response efficiency. Regarding urban renewal, integrating BIM models of multiple buildings to establish a regional 3D architectural database can provide data support for urban planning, urban landscape improvement, and environmental enhancement initiatives, thus contributing to high-quality urban development.

Conclusion

The proposed 3D digital surveying and mapping scheme for building facades, through technological integration and multi-source data collaboration, effectively improves surveying efficiency and accuracy while addressing challenges in complex scenarios. The BIM-based integration and application of surveying results enable these outcomes to play a significant role in building O&M, renovation and refurbishment, emergency management, and urban renewal, thereby expanding their practical value.

In the future, with continuous technological advancement, this scheme is expected to be further refined, providing stronger support for the digital transformation and development of the construction industry.

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