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Accurate facade feature extraction method for buildings from three-dimensional point cloud data considering structural information

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ABSTRACT

Facade features represent segmentations of building surfaces and can serve as a building framework. Extracting facade features from three-dimensional (3D) point cloud data (3D PCD) is an efficient method for 3D building modeling. By combining the advantages of 3D PCD and two-dimensional optical images, this study describes the creation of a highly accurate building facade feature extraction method from 3D PCD with a focus on structural information. The new extraction method involves three major steps: image feature extraction, exploration of the mapping method between the image features and 3D PCD, and optimization of the initial 3D PCD facade features considering structural information. Results show that the new method can extract the 3D PCD facade features of buildings more accurately and continuously. The new method is validated using a case study. In addition, the effectiveness of the new method is demonstrated by comparing it with the range image-extraction method and the optical image-extraction method in the absence of structural information. The 3D PCD facade features extracted by the new method can be applied in many fields, such as 3D building modeling and building information modeling.

1. Introduction

With the development of urban planning, cultural documentation, smart city construction, and building information modeling (BIM), the requirement for realistic three-dimensional (3D) building models has increased (Sajadian, 2014; Cheng et al., 2016; Jordana et al., 2016; Turk, 2016; Aljumaily et al., 2017). Facade features represent a building surface segmentations, such as boundaries of windows, doors, and edges of other significant structural elements, which play an important role in realistic 3D building modeling (Laefer et al., 2011; Hinks et al., 2013). Facade features provide an easy, flexible, and economic way to reconstruct large scale geometric models (Ceylan et al., 2012; AlHalawani et al., 2013). Methods for extracting the facade features of buildings based on 3D point cloud data (3D PCD) are becoming an important research problem due to the amount of valuable information (including corners, edges, and borders) contained in building 3D PCD, (An et al., 2013).

Various methods have been proposed for facade feature extraction from 3D PCD. They mainly involve either direct or indirect extraction. In direct extraction methods, facade features are extracted from raw or pretreated 3D PCD directly by calculating the geometric information, such as distance changes, normal changes, curvature changes, and the density of the 3D PCD (Rutzinger et al., 2009; Tan and Cheng, 2015). Given that the storage of 3D PCD is unstructured, these methods often use random sample consensus (RANSAC), principal component analysis, or fuzzy clustering approaches to segment and cluster the 3D PCD (Schnabel et al., 2007; Biosca and Lerma, 2008; Pang et al., 2015). However, these approaches are only capable of extracting building boundary and contour features (Bauer et al., 2003; Zolanvari and Laefer, 2016). In addition these approaches do not easily simultaneously analyze the feature relationships between different 3D PCD clusters. Therefore, given that direct extraction methods use

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only unstructured 3D PCD to extract facade features, their precision is often very low (Rutzinger et al., 2009; Zolanvari and Laefer, 2016).

In indirect extraction methods, to acquire features with high accuracy, other information, such as range images, optical images, and geo-information, are often included in the facade feature extraction process (Yang et al., 2014, 2016; Gilani et al., 2015). Indirect extraction methods can be divided into two types. The first type constructs range images using 3D PCD first, then extracts features from the range images with the aid of digital-image processing and then maps the range-image features to the 3D PCD (Tan and Cheng, 2015). This type of indirect extraction methods applies range images to extract facade features from 3D PCD to enable detection of edge features of heterogeneous regions. However, this type of indirect extraction methods requires transformation of 3D PCD into two-dimensional (2D) range images. Additionally, only range information associated with 3D PCD is preserved during the transformation process, with loss of substantial amounts of boundary information. Therefore, this type of indirect extraction methods excludes many facade features.

The second type of indirect extraction methods uses 2D optical images obtained by a camera registered on a 3D laser scanner to assist facade feature extraction (Gilani et al., 2015). Considering that high-resolution 2D optical images can supple important information, the second type of indirect extraction methods can acquire extraction results that are more accurate than the first type (Wang et al., 2013; Li et al., 2013; Gilani et al., 2015). However, 2D image processing algorithms are still used to extract 2D features in the second type (Yang et al., 2014, 2016), which does not take advantage of the textural and geometric structural information contained in the 2D optical images of building facades during the extraction process, resulting in the extraction of many non-features while some important facade-features are ignored.

The 2D optical images contain rich textural and geometric structural information that can be used to help extract facade features after adding scales (Fig. 1). The images of building facades contain regular and repetitive textural structural information, such as wall surfaces covered with the same painting material. In addition, there are many window and texture edges with rich simple geometric structural information, such as line segments. This structural information can be used to describe the spatial distribution and internal variation of images. By applying statistical analysis to the structural information of adjacent areas, the marching directions of information can be determined efficiently during the feature extraction process, and these directions are important for improving the feature extraction accuracy (Li et al., 2012; Zhou and Yin, 2013). Thus, structural information can be used in facade feature extraction for 3D PCD but has not been sufficiently utilized in current methods (Truong-Hong et al., 2012; Vo et al., 2015; Aljumaily et al., 2015). This leads to many weaknesses, including decreased accuracy of feature extraction from 2D images of building facades, lack of rigorous mapping models between 2D-image features and 3D PCD, and lack of reasonable optimal treatment of building facade features of 3D PCD. Therefore, it is necessary to investigate methods allowing for higher-accuracy feature extraction from building facades for 3D PCD.

By combining the advantages of both 3D PCD and 2D optical images, we achieved a highly accurate building facade feature extraction method from 3D PCD that considers structural information. Section 2 introduces the basic idea and details of the method. Section 3 describes a case study that extracts the facade features from the 3D PCD of the School of Architectural and Surveying & Mapping Engineering (SASME) building, Jiangxi University of Science and Technology (JXUST). The effectiveness, value settings, and potential limitations of the method are discussed in Section 4. In Section 5, we deliver our conclusions on the validity and accuracy of the method. Our results show that this method can provide data support for 3D modeling and BIM construction in urban planning applications.

2. Methodology

2.1. Basic idea and overall design

The 3D PCD of buildings is unstructured, and the features directly extracted from the 3D PCD often exhibit low geometrical continuity. 2D optical images, which can be mapped to the real-world scale according to the 3D PCD, contain substantial amounts of geometric and textural structural information. This information can be used to describe the spatial distribution and internal variation of image elements, such as line segment features. By applying statistical analysis to the structural information of adjacent areas, the marching directions of information, such as line segments, can be determined efficiently in the feature extraction process, and these directions are very important for improving the accuracy of feature extraction. Therefore, introducing the structural information contained in 2D optical images to the process of feature extraction of building facades from 3D PCD should be feasible and effective.

The overall design of the new method involves three major steps (Fig. 2). First, extract the image features of building facades based on structural information. In this step, the textural and geometric structural information is used to extract image features accurately. Second, explore the mapping method between the image features and the 3D PCD. In this step, we combine image features of building facades and the 3D PCD and then extract the initial 3D PCD facade features based on the image features. Finally, optimize the initial 3D PCD facade features that take into consideration the structural information. In this step, we propose an

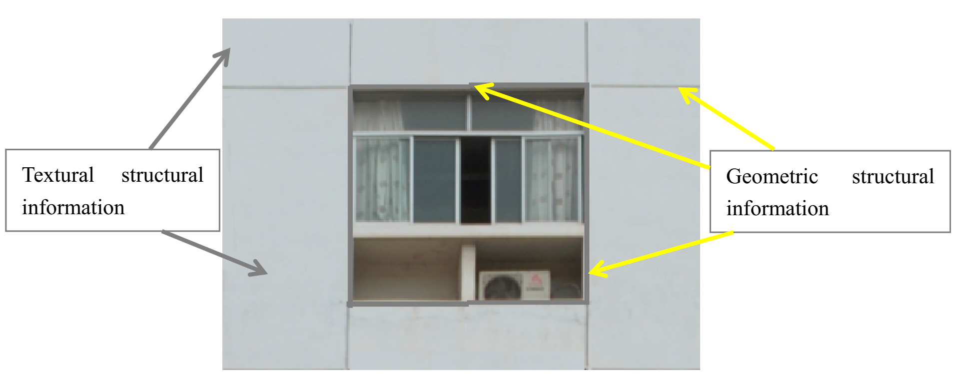

Fig. 1. Schematic diagram of textural and geometric structural information in a facade image.