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Image-driven fuzzy-based system to construct as-is IFC BIM objects

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ABSTRACT

Various new data capturing technologies and object recognition systems have been developed to construct as-is building information models (BIMs) for operations and maintenance (O&M) management of existing buildings. However, a crucial challenge occurs in existing systems when semantic building information is captured under uncontrolled environmental conditions, especially in complex environments with poorly textured features (e.g., no obvious characteristics, edges, points, or lines). This study presents a semiautomatic image-driven system to recognize building objects and their materials and reviews the state-of-the-art object and material recognition methods and systems. A novel semiautomatic image-driven system was developed according to the new neuro-fuzzy framework for recognition of building objects and based on material classification procedures supported by an extensible texture library constructed to recognize their surface materials. More than 600 images were collected for the training process to develop this system, and more than 200 images were used for system verification. The results of the verification experiments show that the developed system can successfully recognize five kinds of building objects (i.e., beams, columns, windows, doors, and walls) and their corresponding surface materials from a single image taken by a handheld digital camera. Furthermore, the recognized building objects are automatically represented in industry foundation classes (IFC), a standard data schema for BIMs. The developed system is highly accurate, robust, and time-efficient for constructing as-is BIM objects in IFC and can help both BIM researchers and practitioners to develop information-rich BIMs in the O&M phase.

1. Introduction

Over the course of a building's life cycle, the operations and maintenance (O&M) phase can cover more than 85% of the total ownership costs and 30 to 50 years of the total lifespan [1]. There are buildings of various ages and in various conditions all around the world. As of the end of 2015, Hong Kong had more than 20,000 buildings older than 30 years, and the government predicts that the number of buildings older than 30 years will approach 30,000 in 2025 [2]. Highly efficient management of existing buildings in the O&M phase is essential for the success and sound development of the construction industry. However, most existing buildings have only as-designed documents (e.g., hard-copy blueprint drawings) that lack timely updates. This traditional document management method without informational support can result in significant information loss during the O&M phase. Moreover, outdated, incomplete, and unreliable as-is information can lead directly to inefficient maintenance, inaccurate decisions, and even accidents [3]. Hence, an appropriate method to efficiently store, exchange, and update O&M information for existing buildings is urgently needed.

The implementation of an as-is building information model (BIM) for existing buildings in the O&M phase has gained significant attention in recent decades [4,5]. Studies have shown that the implementation of a BIM in the O&M phase can greatly minimize information loss and improve management efficiency [6]. However, complete as-is BIMs are not available for most existing buildings. Researchers have developed semiautomatic methods to construct as-is BIMs for existing buildings in terms of data capture and processing, object recognition, and as-is BIM modeling [7,8,33]. As the foremost step in the construction of as-is BIMs, object recognition is used as an information conversion channel to link the simple geometric information embedded in images with computer-readable building components. The development of more intelligent methods for object recognition is thus an emphasis of research, but it represents the most difficult part of constructing an as-is BIM [9]. Moreover, material recognition is crucial for further modeling of semantically rich as-is three-dimensional (3D) models or as-is BIMs [10].

Even if various methods of object recognition and material classification were developed in the computer vision community and the architecture/engineering/construction (AEC) industry, the recognition of objects and their materials under real-world environmental conditions, especially an O&M management environment with poorly textured features (e.g., no obvious edges and poor lighting conditions),

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Fig. 1. Structural components in existing buildings (photos were taken by the author in 2017) (a); various appearances of the same material (b).

would remain a challenge.

Most existing buildings (including interiors and facade) are decorated or painted (e.g., painted in the same color or made of the same material) (Fig. 1(a)). In these complex environments with few features or no distinguishable characteristics (e.g., edges, points, or lines), accurate detection of building objects becomes difficult (Fig. 1(a)). Furthermore, as seen in the comparison of (1) and (2) in Fig. 1(b), the size of a brick unit can change significantly when images are obtained from different distances. As the comparison of (2), (3), and (4) in Fig. 1(b) shows, the brightness and color gradients of this brick material also change remarkably throughout the day. Moreover, the dimensions of the same objects or same units in images also change when they are obtained from different positions or angles [36].

Hence, this study aimed to develop a novel semiautomatic image-driven system to provide an effective (i.e., robust and accurate), convenient (i.e., fluent construction process from images to IFC BIM object), user-friendly (i.e., easily operated), and economical (i.e., requires only a handheld digital camera) method of constructing as-is BIM objects in a building's O&M phase, especially in complex or noisy environments. Based on a comprehensive literature review (Section 2) and preliminary experiments, a novel framework was established to recognize object characteristics (Section 4.1). The proposed image-driven system for constructing as-is BIM objects was then fashioned with three subsystems: an object recognition subsystem (Section 4.2), a material recognition subsystem (Section 4.3), and an IFC BIM generation subsystem (Section 4.4). Within this system, an object recognition approach was developed with the use of a neuro-fuzzy algorithm, and a material classification method with an extensible texture library was constructed. Corresponding IFC representations of the recognized building elements were further created automatically. Finally, a set of experiments was conducted with a university campus building to verify the performance of the proposed system (Section 5). The advantages and limitations of this system are discussed and conclusions are drawn with suggestions for future work in Section 6.

2. Literature review

2.1. Methods to recognize objects from images

It is worthwhile to mention that object recognition in the construction area is influenced by not only the characteristics of construction material images with high similarity (e.g., exposed concrete and concrete painted white) but also the surrounding environment (e.g., surroundings with few features). Generic recognition techniques (e.g., face recognition) are often ineffective in construction-related applications [15]. Further customization and improvement from the generic recognition techniques are needed to address these problems effectively. Various methods such as total station surveying, laser scanning, and image recognition have been developed and adopted to record or report the current conditions of existing buildings [43]. Handheld digital cameras have advantages over their alternatives in their cost-effectiveness, high resolution, and flexible data storage. With rich information (e.g., building object types, materials, geometry) stored in even a single digital image, image recognition methods are an inexpensive, convenient, and time-efficient method [11]. If information can be directly extracted and recognized accordingly from a minimal number of images, great improvements can be made in the efficiency with which as-is BIMs and automation in tracking resources are constructed [45].

According to the types of information adopted, image-driven recognition methods in construction-related fields can be grouped into three categories: appearance-based methods, statistical-/intelligent-algorithm-based methods, and image-based point cloud methods [7]. Appearance-based methods use surface features and object characteristics of collected images, including key features (e.g., points, nodes, edges, and scale/affine-invariant features), surface materials (e.g., color, texture, and reflectivity), and shapes (e.g., 3D geometric primitives). Early works related to object recognition in the construction field referred to the proposed feature-based image recognition method, which successfully identifies building objects from construction site images and facilitates image queries [12]. The method proposed by Son and Kim [13] automatically recognizes 3D structural components using color and 3D data acquired from a stereo vision system. In this method, the color data are used as a guide to detect features, and the 3D geometric data are used to compensate for the pose of the feature. However, only structural components with the same color can be extracted with this method. Furthermore, the structural component recognition method developed by Zhu and Brilakis [14] uses the long vertical lines of columns in an image or video frame via edge detection and Hough transform [58]; however, it only works for concrete columns. To extend the range of object recognition, Brilakis and Soibelman [15] proposed a complementary technique that could identify construction objects automatically based on various shape characteristics by classifying them into nonlinear materials (e.g., concrete walls and concrete slabs) and linear materials with a certain directionality (e.g., steel columns and concrete beams). Furthermore, an automated vision-based algorithm proposed by Hamledari et al. [46] detects the components of indoor under-construction partitions and distinguishes their as-is conditions. According to the shapes and colors of the collected images, this approach [46] uses four computer-vision-based modules, including