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Building extraction from high-resolution optical spaceborne images using the integration of support vector machine (SVM) classification, Hough transformation and perceptual grouping

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ABSTRACT

This paper presents an integrated approach for the automatic extraction of rectangular- and circular-shape buildings from high-resolution optical spaceborne images using the integration of support vector machine (SVM) classification, Hough transformation and perceptual grouping. The building patches are detected from the image using the binary SVM classification. The generated normalized digital surface model (nDSM) and the normalized difference vegetation index (NDVI) are incorporated in the classification process as additional bands. After detecting the building patches, the building boundaries are extracted through sequential processing of edge detection, Hough transformation and perceptual grouping. Those areas that are classified as building are masked and further processing operations are performed on the masked areas only. The edges of the buildings are detected through an edge detection algorithm that generates a binary edge image of the building patches. These edges are then converted into vector form through Hough transform and the buildings are constructed by means of perceptual grouping. To validate the developed method, experiments were conducted on pan-sharpened and panchromatic Ikonos imagery, covering the selected test areas in Batikent district of Ankara, Turkey. For the test areas that contain industrial buildings, the average building detection percentage (BDP) and quality percentage (QP) values were computed to be 93.45% and 79.51%, respectively. For the test areas that contain residential rectangular-shape buildings, the average BDP and QP values were computed to be 95.34% and 79.05%, respectively. For the test areas that contain residential circular-shape buildings, the average BDP and QP values were found to be 78.74% and 66.81%, respectively.

Introduction

Automatic urban-building extraction from space imagery is a challenging problem. Building boundary information is needed for a variety of applications, such as geographic information systems (GIS) database updating, cartography, urban monitoring, 3D city modeling, disaster management and land use analysis. Nowadays, the commercial high-resolution satellite images with multispectral bands provide a potential for the extraction of buildings in urban areas. Building extraction from space imagery has been carried out manually for decades. However, manual object extraction is slow, requires qualified operators and therefore is a costly task. Thus, automatic extraction of buildings is becoming of increasing practical importance.

Automatic building extraction from high-resolution space imagery has been addressed by many researchers. The approach presented by Segl and Kaufmann (2001) for the detection of small objects in high-resolution satellite imagery is based on the shape characteristics. Benediktsson et al. (2003) proposed to use of morphological transformations for the classification and feature extraction from the Indian Remote Sensing 1C (IRS-1C) and Ikonos satellite images of urban areas. Lee et al. (2003) used a class-guided approach to extract buildings from Ikonos images. After obtaining approximate location and shapes of potential buildings, precise delineation was carried out in the panchromatic image using segmentation and squaring. The attempt of Tupin and Roux (2003) for building detection was to the simultaneous use of synthetic aperture radar (SAR) and optical images. The method developed by Haverkamp (2004) is based on edge maps

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derived from the Ikonos panchromatic image. The edge pixels were chained together to obtain the individual sides of buildings and to reconstruct the buildings the logical grouping of these chains were found. Jin and Davis (2005) presented an integrated approach that employs structural, contextual and spectral information for automatic extraction of buildings in high-resolution satellite imagery. Ünsalan and Boyer (2005) introduced an automatic system for street network and house detection from Ikonos satellite images. Kim et al. (2006) proposed a semi-automatic algorithm to extract building lines from monoscopic high-resolution space images. They focused on extracting lines from rectangular-shape buildings of a relatively large size. Sohn and Dowman (2007) utilized a data-driven approach on the optical imagery and a model-driven approach on airborne laser scanning data for extracting rectilinear lines of buildings. The approach proposed by Agüera and Liu (2009) for delineating greenhouses from high-resolution satellites QuickBird and Ikonos comprises the steps of image classification, automatic vectorization, and delineation. Sırmaçek and Ünsalan (2009) detected urban areas and buildings in satellite images through an approach that uses scale invariant feature transform (SIFT) and graph theoretical tools. The approach proposed by Lhomme et al. (2009) for building extraction using very-high-spatial-resolution images is based on discriminating features that have specific size and shape within pixel clusters. Huang and Zhang (2011) presented a morphological building index (MBI) for automatic building extraction from high-resolution remote sensing imagery. In a recent study conducted by Koc-San and Turker (2012) a model-based approach was presented for automatic building database updating from high-resolution space imagery. Their approach utilizes an existing building database as a building-model-library for detecting the buildings from high resolution space imagery.

In the literature, several research studies based on Hough transformation have been reported for the mapping of geological linear features (Karnieli et al., 1996), for the mapping of agricultural plots (Ruiz et al., 2011), for the detection of crop orientation (Chanussot et al., 2005), for the discrimination of the farmland types grassland and cropland (Helmholz et al., 2007), for the detection of natural gas seepages (Van der Werff et al., 2006), for the detection of greenhouses (Agüera and Liu, 2009), and for the detection of buildings (Lee et al., 2003; Croitoru and Doytsher, 2004; Jung and Schramm, 2004; Cui et al., 2012; Grigillo et al., 2012). Lee et al. (2003) proposed a building squaring approach based on the Hough transformation for the detection of the rectilinear building boundaries. Croitoru and Doytsher (2004) employed a Hough transformation to extract straight lines to express building structures. Jung and Schramm (2004) proposed a windowed Hough transformation to detect rectangles and applied it on aerial images to detect rectangular buildings. The approach proposed by Cui et al. (2012) combines the robustness of the Hough transformation with a graph search algorithm for complex building description and extraction from high-resolution remotely sensed imagery. Grigillo et al. (2012) applied the Hough transformation simultaneously with region growing for the extraction of buildings of suburban areas.

In this study, we present an integrated approach to automatic building extraction from high-resolution spaceborne imagery. The particular attention was the extraction of rectangular- and circular-shape (circle, ring, C and S) buildings. Our extraction method is based on the integration of support vector machine (SVM) classification, Hough transformation, and perceptual grouping. The added value of the integration of these approaches is that the integrated strategies offer a better solution compared with individual approaches as the integration of complementary methods helps to overcome the drawbacks of the individual methods. First, we detect the building patches from the image using a binary SVM classification. To increase the reliability of classification the nDSM and NDVI are used as additional bands during image classification. Then, to extract boundaries of the buildings, we sequentially perform edge detection, Hough transformation, and perceptual grouping. To implement the approach we developed a program in MATLAB® v. 7.1 programming environment. We tested our approach on a pan-sharpened and panchromatic Ikonos imagery, covering the selected test areas in Batikent district of Ankara, Turkey. The test areas contain residential and industrial buildings with different shapes, sizes, and usage, as well as various urban-area characteristics. Tests demonstrate the potential of our developed automatic urban-building extraction method. The novelty of this work is that we exploit the combined processing and analysis of SVM classification, Hough transform, and perceptual grouping in building extraction from high resolution spaceborne images. We detect the building patches as the regions of interest areas (ROIs) using the binary SVM classification. By this way, the irrelevant objects are excluded from further processing operations allowing us to focus on the building areas only. With the exclusion of the unnecessary edges form the processing operations the reliability of building boundary extraction is increased. Further, we propose a circular Hough transformation-based approach for the extraction of C- and S-shape buildings.

The remainder of this paper is structured in four parts. First, we describe the proposed method, which comprises the main steps of building detection and building boundary delineation. Then, we provide the experimental tests. In this section we describe the study area, the data used, and the data processing and performance evaluation. We then provide the results obtained from the experimental tests. The last section comprises the conclusions drawn from the presented method.

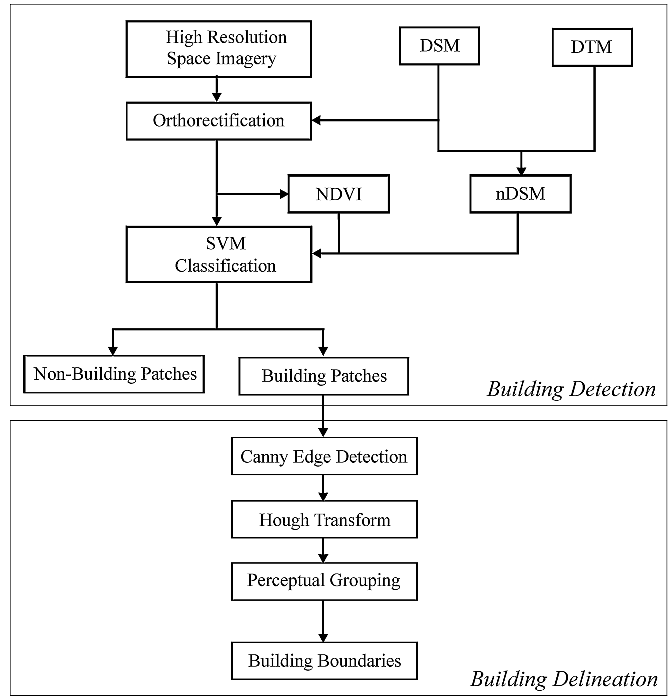

Fig. 1. The schematic workflow of the overall process of the developed building extraction method.

Method

The schematic workflow of the whole process of the proposed building extraction method is shown in Fig. 1. The method requires a high-resolution optical spaceborne image with multi-spectral bands, digital surface model (DSM) and digital terrain model (DTM)