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Satellite images analysis for shadow detection and building height estimation

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ABSTRACT

Satellite images can provide valuable information about the presented urban landscape scenes to remote sensing and telecommunication applications. Obtaining information from satellite images is difficult since all the objects and their surroundings are presented with feature complexity. The shadows cast by buildings in urban scenes can be processed and used for estimating building heights. Thus, a robust and accurate building shadow detection process is important. Region-based active contour models can be used for satellite image segmentation. However, spectral heterogeneity that usually exists in satellite images and the feature similarity representing the shadow and several non-shadow regions makes building shadow detection challenging. In this work, a new automated method for delineating building shadows is proposed. Initially, spectral and spatial features of the satellite image are utilized for designing a custom filter to enhance shadows and reduce intensity heterogeneity. An effective iterative procedure using intensity differences is developed for tuning and subsequently selecting the most appropriate filter settings, able to highlight the building shadows. The response of the filter is then used for automatically estimating the radiometric property of the shadows. The customized filter and the radiometric feature are utilized to form an optimized active contour model where the contours are biased to delineate shadow regions. Post-processing morphological operations are also developed and applied for removing misleading artefacts. Finally, building heights are approximated using shadow length and the predefined or estimated solar elevation angle. Qualitative and quantitative measures are used for evaluating the performance of the proposed method for both shadow detection and building height estimation.

1. Introduction

Building shadows can be used for estimating the structure and height of the corresponding buildings. This information can be utilized in many telecommunication or remote sensing applications such as natural disaster monitoring, urban change detection, urban scene reconstruction, cartography update, urban inventory and wireless network planning (Cheng and Han, 2016; Dubois et al., 2016; Liu et al., 2015; Hu et al., 2003; Chen et al., 2005; Karantzalos and Paragios, 2010). For a successful satellite image analysis and height estimation of building structures, the complexity and spectral heterogeneity that often exist in urban landscape scenes has to be handled properly and shadows should be accurately detected and isolated.

Shadows are usually cast when objects totally or partially occlude direct light from a source of illumination. In remote sensing and telecommunication literature, various methods have been used for shadow detection using satellite images. These are often classified into two categories, the so-called property-based and the model-based methods (Arevalo et al., 2008; Adeline et al., 2013). In property-based methods, spectral and spatial features of shadow regions are utilized (Nagao et al., 1979; Dare, 2005; Chen et al., 2007; Sırmacek and Unsalan, 2008; Ye et al., 2012; Tsai, 2006; Chung et al., 2009). Model-based methods make use of additional metadata or scene information such as sensor localization data, light source direction and objects geometry as priori knowledge (Li et al., 2005; Lorenzi et al., Sep. 2012; Shao et al., 2011). Methods based on histogram threshold techniques are extensively investigated for shadow detection because of their simplicity. Simple linear methods, bimodal histogram splitting, the number of peaks and valleys and local minimum value derived from the grayscale histogram of satellite images, are some of the techniques used for selecting the most appropriate threshold value for shadow segmentations (Nagao et al., 1979; Dare, 2005; Chen et al., 2007; Sırmacek and Unsalan, 2008). Many of the studies as

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reported in literature have considered the misclassification of sunlit dark objects classified as shadows and shadowed bright objects classified as non-shadow regions, as an important drawback that should be addressed (Arevalo et al., 2008; Dare, 2005; Chen et al., 2007; Ye et al., 2012; Tsai, 2006; Chung et al., 2009). Thus, several researchers utilized invariant colour models to overcome this issue. A Region-based algorithm integrating colour invariants and edges for locating shadows in imagery acquired from the earth observation satellite system QuickBird, has been proposed by Arevalo et al. (2008). Dare (2005) and Chen et al. (2007) utilized texture information to eliminate non-shadow dark regions. Ye and Xu proposed a threshold model where shadows on urban aerial true colour and colour infrared images were detected by using the Hue, Saturation and Intensity (HSI) representation of the image (Ye et al., 2012). Tsai performed a detailed comparative study on shadow compensation of colour aerial images in invariant colour models, and a spectral ratio between hue and intensity was developed and used to detect shadow regions (Tsai, 2006). Chung et al. extend Tsai's work and improved the spectral ratio estimation process (Chung et al., 2009). Among the various methods, curve evolution schemes like active contour and level set models are used to segment the satellite images (Niu, 2006; Cao et al., 2005; Karantzalos and Argialas, 2008; Karantzalos and Paragios, 2009; Chan and Zhu, 2003; Cremers et al., 2006; Peng et al., 2005; Ahmadi et al., 2010; Liasis and Stavrou, 2013; Elbakary and Iftekharuddin, 2014; Manno-Kovacs and Sziranyi, 2015). These methods revealed promising results because of their ability to cope well with topological changes. Recently, Mohamet and Iftekharuddin proposed a region-based active contour model for detecting the shadows of man-made buildings in high resolution panchromatic satellite images by encoding a predefined radiometric value for describing shadow regions (Elbakary and Iftekharuddin, 2014).

A few attempts have been reported in literature where shadow information is used for estimating building heights. Irvin and McKeown used shadows along with information about the solar elevation angle in aerial photographs to recover the shape and height of buildings (Irvin and Mckeown, 1989). Shettigara and Sumerling described a method of determining building heights based on their extended features and the shadows they cast (Shettigara and Sumerling, 1998). The building shadows were also used by Cheng and Thiel (1995) and Turker and Sumer (2008), to calculate the height of buildings that collapsed in an earthquake.

The work presented in this paper involves with the evaluation and optimization of the active contour models for building shadows detection in the presence of spectral heterogeneity and feature complexity. An automated emphasized method for delineating building shadows and estimating the corresponding building heights as presented in monocular Google Earth satellite images is proposed. In traditional active contour segmentation models, the mean intensity values and their distribution are often used as region descriptors. However, applying a region-based active contour model for selectively detecting building shadows is difficult since several regions or objects are presented with similar intensities or characteristics as building shadows. Furthermore, intensity heterogeneity that often exists in shadow regions leads to erroneous segmentations. Thus, a customized filter is developed for enhancing the shadows and reducing intensity heterogeneity. To achieve this, spectral and spatial analysis of the satellite image is performed. An automated scheme for selecting the most appropriate parameters and designing the optimized filter is proposed. The radiometric property of shadows is automatically estimated and encoded with the proposed filter in an active contour model. A new energy term able to bias the contours to detect shadow regions is formed. Morphological and variance threshold operations are applied for eliminating misleading non-building shadow regions from the shadow segmentation mask. Finally, the detected building shadows are analysed further for estimating the heights of the corresponding buildings. The shadow length and the predefined solar elevation angle are used for calculating the height of the presented buildings by applying simple trigonometric functions. In those cases where the solar elevation angle is unknown, indices from the building shadow segmentation mask are used for estimating it.

This paper is organized as follows. Section 2 describes briefly the spectral and spatial satellite image analysis for shadow enhancement. Section 3 introduces active contour segmentation models. Section 4 presents the development of the proposed model for building shadow detection and building height estimation. The experimental results are presented and discussed in Section 5. Finally the paper concludes in Section 6 with some recommendations for further work.

2. Spectral and spatial image analysis for shadow enhancement

The aim of spectral and spatial analysis of the satellite images is to develop a filter able to enhance shadow regions and subsequently improve the overall performance of a building shadow detection process using an active contour segmentation model. With special consideration to the typical types of satellite images, a shadow enhancement method should result in improving the clarity and homogeneity of the shadow and non-shadow regions as presented in landscape urban scenes.

The spatial frequency transform is a widely used tool for image analysis. The image signal is represented in terms of magnitude and phase. The importance of spectral analysis in images is noticed in a variety of applications. Usually the content of image signal is not stationary thus the localized frequency analysis has become an important and powerful image processing tool (Szeliski, 2011). Moreover it is advantageous to analyse the signal frequency and spatial information simultaneously using various tools such as Short Time Fourier Transform (STFT), Gabor Transform (GT) and Wavelet Transform (Gonzalez and Woods, 2008). Gabor filters were originally introduced by Gabor (1946) and extended into two dimensions by Daugman (1980, 1985). Gabor filters are used extensively in image processing and computer vision because of their optimal localization properties in both spatial and frequency domains (Jain et al., 1997; Yuan et al., 2014; Tzotsos et al., 2011; Sirmacek and Unsalan, 2011; Xiao et al., 2010). This work utilises both the local phase and magnitude response of a Gabor filter for enhancing shadows displayed in satellite images.

The Gabor filter is a two-dimensional filter formed by the combination of a cosine with a two-dimensional Gaussian function and it has the following general form:

$$g(x, y, \theta, f, \sigma_x, \sigma_y) = \exp\left\{-\frac{1}{2}\left[\frac{x_\theta^2}{\sigma_x^2} + \frac{y_\theta^2}{\sigma_y^2}\right]\right\}\cos(2\pi f x_\theta),$$
$$x_\theta = x\cos\theta + y\sin\theta, y_\theta = -x\sin\theta + y\cos\theta \tag{1}$$

where θ denotes the rotation of the filter related to the x-axis and f denotes the local frequency. The Gabor filter as presented above is centred at the origin and the standard deviations of the Gaussian function along the x-axis and y-axis are presented as σ_x and σ_y, respectively.

A Gabor filter for enhancing the shadows as presented in satellite images can be designed by thoroughly investigating and subsequently selecting the most appropriate parameters of the corresponding function. The implementation of Gabor filters, follow mainly two directions, the filter design approach and the filter bank approach (Bianconi and Fernándezb, 2007). In the filter design methods the parameters are chosen by considering the available data and the expected result. In the filter bank methods the filter