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A multi-band approach to unsupervised scale parameter selection for multi-scale image segmentation

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ABSTRACT

Image segmentation is one of key steps in object based image analysis of very high resolution images. Selecting the appropriate scale parameter becomes a particularly important task in image segmentation. In this study, an unsupervised multi-band approach is proposed for scale parameter selection in the multi-scale image segmentation process, which uses spectral angle to measure the spectral homogeneity of segments. With the increasing scale parameter, spectral homogeneity of segments decreases until they match the objects in the real world. The index of spectral homogeneity is thus used to determine multiple appropriate scale parameters. The performance of the proposed method is compared to a single-band based method through qualitative visual interpretation and quantitative discrepancy measures. Both methods are applied for segmenting two images: a QuickBird scene of an urban area within Beijing, China and a Woldview-2 scene of a suburban area in Kashiwa, Japan. The proposed multi-band based segmentation scale parameter selection method outperforms the single-band based method with the better recognition for diverse land cover objects in different urban landscapes.

1. Introduction

The fidelity provided by very high resolution (VHR) data from IKONOS, QuickBird, GeoEye-1 and WorldView-2, has proven useful for numerous applications, such as impervious surface mapping (Lu et al., 2011; Lu and Weng, 2009; Yuan and Bauer, 2006) and tree crown delineation (Ardila et al., 2012; Mallinis et al., 2008; Song et al., 2010). Furthermore, object based image analysis (OBIA) yields better accuracy compared to traditional pixel-based image analysis (Cleve et al., 2008; Yan et al., 2006; Yuan and Bauer, 2006) when high within-class spectral variability occurs (Johansen et al., 2010). Of the first stage of OBIA, the aforementioned literature suggests that image segmentation is the most influential on land cover object recognition. Consequently, several image segmentation algorithms have been proposed including region-growing segmentation (Benz et al., 2004), watershed segmentation (Li et al., 2010; Li and Xiao, 2007; Wang et al., 2004), and mean-shift segmentation (Comaniciu and Meer, 2002). Moreover, many image segmentation algorithms have been expanded to consider objects at multiple scales, since ground objects generally show multi-scale features in high resolution image (Blaschke, 2010; Bruzzone and Carlin, 2006; Hay et al., 2003). For instance, at fine scales a grass field may have spectral variability or patchiness related to micro-moisture regimes or worn patches dues to sporting events while at coarser scales the field in its entirety stands out from the surrounding urban environment. As such, multi-scale image segmentation addresses some of the deficiencies associated with single scale segmentation in complex land cover environments (Akçay and Aksoy, 2008; Carleer and Wolff, 2006; De Roeck et al., 2009; Li et al., 2011; Tilton et al., 2012)

In image segmentation, the appropriate scale parameter is not readily apparent and is currently chosen by time consuming and subjective trial-and-error (Meinel and Neubert, 2004; Zhang et al., 2008). In lieu of trail-and-error approaches, several scale parameter selection methods have been proposed typically utilizing measures of the dissimilarity between a segmentation result and a reference image in which the optimal scale parameter is the best match to the reference image (Carleer et al., 2005; Chabrier et al., 2006; Liu et al., 2012; Möller et al., 2007; Neubert et al., 2008; Tong et al., 2012). In addition, Espindola et al. (2006) and Johnson and Xie (2011) selected the optimal segmentation scale parameter by assessing

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intra-segment homogeneity using weighted variance of the NIR band and inter-segment heterogeneity using spatial autocorrelation (Global Moran's I). Kim et al. (2008, 2009) identified the optimal scale parameter for segmenting forest stands through computing unweighted variance and Global Moran's I. In contrast, Dragut et al. (2010) developed an automatic single-band method for defining meaningful segmentation scale parameters across a range of different image types and landscapes. Further, a few studies have also paid attention on selecting more than one appropriate scale parameter for multi-scale image segmentation (d'Oleire-Oltmanns et al., 2013; Dragut and Eisank, 2011; Dragut et al., 2011; Dragut et al., 2010; Trias-Sanz, 2005; Trias-Sanz et al., 2008).

Single-band based segmentation scale parameter selection approaches may be suitable for some environments featuring strong spectral contrasts such as forests. The objects that comprise a forest consistently feature strong gradients in NIR reflectance such that the choice of band to base heterogeneity upon is obvious. Since single-band scale parameter selection assumes a contrasting reflectance between objects it may have difficulty discriminating objects with spectrally similar signatures, especially within complex environments where multiple objects with different spectral characteristics dominate the scenes. In an urban context, the variety of materials, diversity of forms and prevalence of mixed pixels the likelihood of all objects contrasting in a sole band is substantially decreased. Furthermore, we may expect that man-made materials, such as metal, asphalt and concrete, which have minimal variability in the NIR region, may feature strong variability in the visible light region on account of painting, special coatings or even age. However, the utility of multi-band methods to determine the appropriate segmentation scale parameter has not been examined and a comprehensive review indicated that few studies have examined multiple band image segmentation of a VHR image. This study proposes a new unsupervised method of scale parameter selection for multi-scale image segmentation, which simultaneously uses multiple bands of a VHR image. A series of appropriate segmentation scale parameters are identified to delineate various scales of land cover objects. Segmentation performance is qualitatively and quantitatively assessed in comparison with a unsupervised single-band approach (Espindola et al., 2006; Johnson and Xie, 2011).

2. Methods

The appropriate scale parameters were determined by evaluating the spectral homogeneity post image segmentation conducted across a range of tested scale parameters. The image segmentation method adopted in this study was multi-resolution non-hierarchical segmentation (MRS) algorithm, a commonly used segmentation algorithm implemented in eCognition Developer 8.7. Segmentation occurs by defining small groups of pixels as segments and merging similar neighboring segments together in subsequent steps until a heterogeneity threshold, set by the scale parameter is reached (Benz et al., 2004). Optimally, the final segments will have the geometrical shape and boundary as per the real world objects present in the image. As the segments grow, the spectral homogeneity decreases till the point they match the objects in the real world size. Spectral homogeneity of the segments was measured as the spectral angle (Kruse et al., 1993) between each pair of two pixels within the segment. The index (Θ_{AMEAN}) measuring the spectral homogeneity of segments were used for segmentation scale parameter selection.

2.1. Spectral homogeneity of segments measured by spectral angle

Spectral angle is a common distance metric for two spectra comparison (Kruse et al., 1993). The reflectance spectra of individual pixel can be described as vectors in an n-dimensional space, where n is the number of spectral bands. Each pixel vector has a certain length and direction. The length of the vector represents brightness of the pixel while the direction represents the spectral characteristics of the pixel. Difference of illumination mainly influences the length of the vector, while spectral distance between different pixels is measured by the angle between their corresponding vectors (Luc et al., 2005). The more similar the two spectra are, the smaller the spectral angle between them. The spectral angle is defined by the expression given in Eq. (1):

$$\theta_{(a,b)} = \cos^{-1}\left(\frac{\sum_{i=1}^{n} a_i b_i}{\sqrt{\sum_{i=1}^{n} a_i^2 \sum_{i=1}^{n} b_i^2}}\right) \quad (1)$$

where n represents the number of spectral bands, a_i and b_i represent the reflectance spectra component i of two different pixels, respectively.

Since the spectral angle quantifies the spectral difference between two pixels, it is reasonable to use it to measure spectral homogeneity. Spectral angles between each pair of two pixels in a segment were calculated to determine the mean value. The mean Θ_{AMEAN} for all segments was produced by averaging the value for each segment in the entire image. In particular, the validation of spectral homogeneity measurement using the mean spectral angle was quantitatively compared with a single-band based metric (variance) before appropriate segmentation scale parameter selection.

2.2. Appropriate segmentation scale parameter selection

With the increasing scale parameter, spectral homogeneity of a segment thus decreases while the index of mean spectral angle increases. When a segment nearly matches the object in the image, the decreasing spectral homogeneity will accelerate, because of edge effects and the increased likelihood of mixed pixels cause greater spectral heterogeneity at the object's edge in comparison to the objects center. Furthermore, the object boundaries will be preserved in segmentation at a number of higher levels, where the homogeneity of this object remains the same (Dragut et al., 2010). When segments just match the representative objects, the increasing tendency of Θ_{AMEAN} will suddenly reduce or stop, because spectral homogeneity of segments almost remains the same right after the appropriate scale parameter is reached. In order to discover the variation of spectral homogeneity from a scale level to other, the derivative of Θ_{AMEAN} with respect to scale parameter l were calculated using Eq. (2):

$$\dot{\Theta}_{AMEAN}(l) = \frac{d\Theta_{AMEAN}(l)}{dl} = \frac{\Theta_{AMEAN}(l) - \Theta_{AMEAN}(l-\Delta l)}{\Delta l} \quad (2)$$

where $\Theta_{AMEAN}(l)$ is the average of mean spectral angles at segmentation scale parameter l.

Based on above statement, when segments at segmentation scale parameter $l-\Delta l$ nearly match the appropriate segmentation at scale parameter l, $\dot{\Theta}_{AMEAN}(l)$ is usually greater than both $\dot{\Theta}_{AMEAN}(l-\Delta l)$ and $\dot{\Theta}_{AMEAN}(l+\Delta l)$. Thus, a local peak (LP) in the curves of $\dot{\Theta}_{AMEAN}(l)$ is generated. An LP was considered as a signal of the appropriate scale parameters for multi-scale image segmentation. To highlight the expression of each peak, an LP index I_{LP} was derived as given by Eq. (3):

$$I_{LP} = \left(\dot{\Theta}_{AMEAN}(l) - \dot{\Theta}_{AMEAN}(l-\Delta l)\right) + \left(\dot{\Theta}_{AMEAN}(l) - \dot{\Theta}_{AMEAN}(l+\Delta l)\right) \quad (3)$$

The scale parameters at which relatively greater LPs (i.e. with high I_{LP} values) occur were considered as the more suitable segmentation scale parameters in this study. Since ground objects with different size co-exist in an image, it is very likely that several LPs will be identified for the image.