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Classification of visible and infrared hyperspectral images based on image segmentation and edge-preserving filtering

Binge Cui [a,*], Xiudan Ma [a], Xiaoyun Xie [a], Guangbo Ren [b], Yi Ma [b]

[a] College of Computer Science and Engineering, Shandong University of Science and Technology, Qingdao 266590, China
[b] The First Institute of Oceanography (FIO), State Oceanic Administration (SOA), Qingdao 266061, China

HIGHLIGHTS

- Edge-preserving filtering is applied to remove the noise while preserving boundaries.
- Three kinds of spatial information are combined to improve the classification result.
- Visible and infrared bands are jointly used to improve the classification accuracies.
- The proposed method can achieve high classification accuracy with a few samples.

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ABSTRACT

The classification of hyperspectral images with a few labeled samples is a major challenge which is difficult to meet unless some spatial characteristics can be exploited. In this study, we proposed a novel spectral-spatial hyperspectral image classification method that exploited spatial autocorrelation of hyperspectral images. First, image segmentation is performed on the hyperspectral image to assign each pixel to a homogeneous region. Second, the visible and infrared bands of hyperspectral image are partitioned into multiple subsets of adjacent bands, and each subset is merged into one band. Recursive edge-preserving filtering is performed on each merged band which utilizes the spectral information of neighborhood pixels. Third, the resulting spectral and spatial feature band set is classified using the SVM classifier. Finally, bilateral filtering is performed to remove "salt-and-pepper" noise in the classification result. To preserve the spatial structure of hyperspectral image, edge-preserving filtering is applied independently before and after the classification process. Experimental results on different hyperspectral images prove that the proposed spectral-spatial classification approach is robust and offers more classification accuracy than state-of-the-art methods when the number of labeled samples is small.

1. Introduction

Hyperspectral remote sensing is a major breakthrough in remote sensing technology that can simultaneously acquire hundreds of spectral bands from visible light to near infrared light, each of which span approximately 10 nm. Hyperspectral images contain a wealth of spectral information that makes it possible to finely classify ground objects. However, as shown in the Hughes phenomenon [1], when the number of samples is limited, the classification accuracy will decrease as the number of bands increases. Thus, dimensionality reduction is critical to improve the classification accuracy of hyperspectral image. To achieve this, feature selection and feature extraction have been widely studied in recent years [2–4].

The goal of feature selection is to find the subsets of the spectral bands that provide the highest class separability [2]. Depending on whether labeled samples are required or not, feature selection algorithms can be broadly classified into two categories: supervised methods and unsupervised methods [5]. Unsupervised methods such as simplex-based feature selection methods [6] and cluster-based feature selection methods [7] select the most informative and distinctive features, while supervised methods typically require a search strategy [8–10] and a criterion function [11–14]. The feature subset with the best criterion function value determines the output of the feature search method.

Unlike feature selection, feature extraction can effectively remove noise in the extracted features using certain types of linear transformations. Feature-extraction algorithms can also be

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* Corresponding author.
E-mail address: cuibinge@qq.com (B. Cui).

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classified as supervised and unsupervised methods. Principal Component Analysis (PCA) [15], Maximum Noise Fraction (MNF) [16] and Independent Component Analysis (ICA) [17] are unsupervised methods, while Linear Discriminant Analysis (LDA) [18] is one supervised method. Both supervised and unsupervised methods can transform a hyperspectral image from a high-dimensional space to a low-dimensional space meanwhile preserving most of the desired information in a few principal components.

In the remote sensing image, the adjacent pixels are likely to belong to the same category. Inspired by this, many researchers have worked on spectral-spatial classification methods that can incorporate spatial information into the classification process [19,20]. Spectral-spatial classification methods include numerous categories including fixed-window based methods (e.g., morphological filtering [21], Markov random fields (MRFs) [22] and texture measures [23]); spectral-spatial kernel based methods (e.g., morphological kernel [24], composite kernel [25] and graph kernel [26]); and image segmentation based methods (e.g., partitional clustering [27], watershed transformation [28] and hierarchical segmentation [20]). These methods can be combined to further improve the classification accuracy of hyperspectral images [29]. Spectral-spatial classification methods can eliminate "salt-and-pepper" noise on classification maps and can markedly improve image-classification accuracy.

Recently, edge-preserving filtering has been applied successfully in many applications such as image fusion [30], image denoising [31] and image classification [32,33]. In principle, edge-preserving filtering is a type of low-pass filter that can smooth out small changes while making the edges of objects clearer. Unlike traditional low-pass filters, spatial and spectral distances are jointly used for each pixel to define the weights of its neighborhood pixels in edge-preserving filters. Thus, neighborhood pixels that lie on the same side of a strong edge will have larger weights, while those that lie on the opposite sides of a strong edge will have a negligible weight. In hyperspectral image classification, edge-preserving filtering can be applied to improve the image quality or to improve the classification map.

In this study, image segmentation and edge-preserving filtering technologies are jointly utilized to improve the classification accuracy of hyperspectral images. The proposed method is based on two facts: (1) the pixels belonging to a homogeneous region should be classified as one class; (2) the neighboring pixels usually have strong correlations with each other. Based on the first fact, object-oriented image segmentation is performed to output a lot of homogeneous regions. The pixels within one region are given the same region number. Based on the second fact, edge-preserving filtering is utilized to ensure that neighboring pixels on the same side of an edge have similar features and belong to the same class. To achieve this, different types of edge-preserving filtering are applied independently before and after the classification process. Experiment results show that the proposed method can improve the classification accuracy of SVM significantly.

The remainder of this paper is organized as follows. Section 2 introduces an object-oriented image segmentation algorithm and two widely used edge-preserving filters (EPFs). Section 3 describes the proposed spectral-spatial classification approach. The experimental results are presented in Section 4, and conclusions are given in Section 5.

2. Image segmentation and edge-preserving filtering

In the past ten years, image segmentation and edge-preserving filtering techniques have made marked progress. In this section, some typical image segmentation and edge-preserving filtering techniques are introduced.

2.1. Object-oriented image segmentation

Image segmentation attempts to divide an image into spatially continuous and homogenous regions. Each pixel belongs to a region, and all the pixels belonging to one region are spectrally similar and spatially adjacent. Among various segmentation algorithms, object-oriented image segmentation has been widely used to analyze remote sensing images, which can produce image objects known as "patches" in landscape ecology. One of the most noteworthy object-oriented image segmentation methods—multi-resolution segmentation—has been proposed and carried forward by the well-known commercial eCognition software [34,35]. Color criterion and shape criterion are jointly used to create homogeneous image objects. The segmentation function is constructed as follows:

$$S_f = \omega_{color} \cdot h_{color} + (1 - \omega_{color}) \cdot h_{shape} \tag{1}$$

where h_{color} is the color criterion that measures changes in spectral heterogeneity, h_{shape} is the shape criterion that measures changes in the shape heterogeneity, ω_{color} is the weight of h_{color}, and $1 - \omega_{color}$ is the weight of h_{shape}. Spectral heterogeneity is calculated using the standard deviation of the spectral values multiplied by the corresponding weights, while shape heterogeneity is calculated using two types of landscape ecology measures: compactness and smoothness. For a complete description of multi-resolution image segmentation, please refer to the original study in Ref. [35].

2.2. Edge-preserving filtering

During the last decade, many different EPFs (e.g., joint bilateral filter [36], weighted least-squares (WLS) filter [37], guided filter [38] and domain transform filter [39]) have been proposed. The primary advantage of edge-preserving filtering is that edges become clearer after filtering rather than becoming blurred. Most of these EPFs provide a different weight calculation method for the neighborhood pixels, which makes pixels about the same distance away from the current pixel have different weights. Pixels on the same side of the current pixel will have a larger weight, while pixels on a different side of the current pixel will have a smaller weight. In the following sections, two widely used edge-preserving filtering methods—joint bilateral filtering and domain transform recursive filtering—will be described in detail.

2.3. Joint bilateral filtering

Compared to other low-pass filters, bilateral filtering has the ability to maintain the edge information of images when smoothing. In addition to the geometric distance, the color distance between pixels is used in the calculation of the neighboring pixel weights. The bilateral filter has two weights—one is based on the geometric distance, while the other is based on the color distance. Joint Bilateral Filtering (JBF) is an improved bilateral filtering method in which the color distance is calculated based on the color differences between pixels in a guidance image that has lower noise and sharper edges. Specifically, a joint bilateral filter applied to an input image f(x) and its corresponding guidance image g(x) produces an output image h(x) defined as follows:

$$h(x) = k^{-1}(x)\sum_{\Omega} f(\xi)c(\xi, x)s(g(\xi), g(x)) \tag{2}$$

with the normalization:

$$k(x) = \sum_{\Omega} c(\xi, x)s(g(\xi), g(x)) \tag{3}$$