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ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Manifold structure preservative for hyperspectral target detection

Maryam Imani

Faculty of Electrical and Computer Engineering, Tarbiat Modares University, Tehran, Iran

Received 21 August 2017; received in revised form 17 February 2018; accepted 21 February 2018

Abstract

A nonparametric method termed as manifold structure preservative (MSP) is proposed in this paper for hyperspectral target detection. MSP transforms the feature space of data to maximize the separation between target and background signals. Moreover, it minimizes the reconstruction error of targets and preserves the topological structure of data in the projected feature space. MSP does not need to consider any distribution for target and background data. So, it can achieve accurate results in real scenarios due to avoiding unreliable assumptions. The proposed MSP detector is compared to several popular detectors and the experiments on a synthetic data and two real hyperspectral images indicate the superior ability of it in target detection.

Keywords: Local structure; Feature transformation; Target detection; Hyperspectral image

1. Introduction

Analyzing a wide range of different land cover materials has been simplified by using hyperspectral remote sensing images. The rich spectral dimensionality of hyperspectral images allows to discriminate between different materials with higher details than multispectral ones. Hyperspectral images containing both the spectral and spatial information have been used in many classification problems (Wang et al., 2014; Li et al., 2017; Yang and Crawford, 2016; Liu et al., 2016; Imani and Ghassemian, 2017). Moreover, separation of a few target pixels such as man-made objects or certain materials is one of the most important applications of hyperspectral data (Qin et al., 2009; Wang et al., 2012; Zhao et al., 2014; Wang and Xue, 2017; Zhang et al., 2017). This separation is possible due to this fact that the amount of reflectance varying with the wavelength is unique for each material. In other words, the spectral signature plays the role of a fingerprint for identification of any given material.

The testing pixels in the hyperspectral images can be assumed to have a statistical distribution characteristic such as normal distribution. The generalized likelihood ratio test can be simply used to construct a target detector. The well known methods such as spectral matched filter (SMF) (Robey et al., 1992) and matched subspace detector (MSD) (Scharf and Friedlander, 1994) assume that both of hypotheses obey a normal distribution where they only differ in their means. While SMF considers just a feature vector as the spectral signature of target, MSD uses a target subspace consisting of some available target training samples. Another subspace-based target detector is adaptive subspace detector (ASD) which includes a linear matrix model (Kraut et al., 2001). ASD has been successfully implemented for detection of subpixel targets (Li et al., 2015).

Sparsity based techniques have been also used for hyperspectral image analysis in recent years. The sparsity based target detector (STD) sparsely represents each testing pixel image by a few training samples including both target and background samples (Chen et al., 2011). The reconstruction residuals are directly employed to perform the

E-mail address: maryam.imani@modares.ac.ir

https://doi.org/10.1016/j.asr.2018.02.027
0273-1177/

Please cite this article in press as: Imani, M. Manifold structure preservative for hyperspectral target detection. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.02.027

detection. One of the main advantages of STD is that there is no assumption on the statistical distribution of data as the previous target detectors. A low rank and sparse representation based anomaly detection method has been proposed in (Xu et al., 2016). This method is formed based on this idea that the lowest rank representation of hyperspectral image contains the background information. The anomaly part of image can be obtained by subtracting the background recovered by the lowest rank representation from the original image. In this way, the relationship of all hyperspectral image pixels is considered from a global viewpoint. In addition, to involve the local structure of hyperspectral data, a sparsity criterion is considered, which results in an accurate representation of data.

Many eigenspace projection methods have been introduced for feature transformation in hyperspectral image classification. Laplacian eigenmap (LE) (Tu et al., 2011), locally linear embedding (LLE) (Kim and Finkel, 2003), local preserving projection (LPP) (He and Niyogi, 2004), and neighborhood preserving embedding (NPE) (He et al., 2005) are among the widely used manifold learning based feature transformations. They are used to preserve the locality of data structure. LLE and NPE preserve the local neighborhood structure by minimizing the reconstructed error of data samples. LPP maintains the topological structure of data by solving a minimization problem through an adjacency graph.

The manifold learning based feature transformations usually are known as unsupervised approaches. But, they can be implemented supervised too. Unsupervised LPP generates the similarity matrix without using the class label information while supervised LPP considers only samples within the same class during graph construction. In other words, in supervised LPP only the similarities between samples belonging to the same class are measured and the similarities between different classes are not measured.

In addition to manifold learning based methods (Ziemann et al., 2015; Zhang et al., 2014), the metric learning techniques have been also known as effective approaches for hyperspectral processing problems such as in classification ones. But, few studies are done for using them in target detection applications (Zhang et al., 2014; Du and Zhang, 2014). Although target detection is a two-class classification problem, but due to unbalanced number of target and background samples and limited number of targets, the use of metric learning methods as the same ones used for classification is not so efficient.

The metric learning methods generally learn a specific matrix to discriminate samples from different classes. Neighborhood component analysis (NCA) maximizes a leave-one-out K-nearest neighbors score on the training samples to learn the distance metric (Goldberger et al., 2004). Discriminative component analysis (DCA) uses the nonlinear relationships between data samples and the contextual information (Hoi et al., 2006). Large margin nearest neighbor (LMNN) learns the metric by minimizing distance between nearest neighbors and maximizing margin between samples from different classes (Weinberger and Saul, 2009). The random forest metric learning (RFML) algorithm combines random forests with semi-multiple metrics to increase separation between targets and background samples (Dong et al., 2015).

Hyperspectral target detection deals with main challenges because of appearance of targets as subpixels (Niu and Wang, 2017). Because of the low number of targets in the image scene and also because of the restriction in the spatial resolution of hyperspectral image, usually target and background pixels are excessively mixed together and this issue produces false alarm and low probability of target detection in the detector output. In other words, targets and background are located in a near distance respect together in the spectral feature space. So, it is necessary to make them as far as possible from each other. But, the local structure of targets should be preserved too. In respect to these aspects, a target detection based on metric learning is proposed in this paper which is termed as manifold structure preservative (MSP). While methods such as SMF, MSD, and ASD consider a Gaussian distribution for background and target signals, the MSP target detector is free of any assumption about data distribution. So, it can achieve good performance in real scenarios with complicated background clutter and subpixel targets where a Gaussian distribution is not enough to model data. The proposed MSP detector in this work optimizes three objective functions which one of them is similar to NPE and LLE and one of them is like LPP. The third objective function is considered to increase the discrimination between target and background samples.

The efficiency of MSP is compared with some popular and state-of-the-art target detectors in terms of probability of detection and also the computation time. The experimental results show the superior performance of MSP for target detection in one synthetic data and two real hyperspectral images.

2. The proposed MSP detector

Hyperspectral target detection is a challenging problem. Although the high spectral resolution of hyperspectral images simples the discrimination between different materials even with similar spectral signatures, but because of restriction in the spatial resolution of hyperspectral sensors, targets usually appear as subpixels in the hyperspectral images. Moreover, the occurrence probability of targets is low and background clutter is the dominant part of image. So, depending on available land cover classes within each pixel of image, a target pixel can appear as a mixed pixel where there are both of target and multiple background classes. Therefore, often target and background signals are mixed together.

To deal with these problems, a target detection method based on metric learning is proposed in this paper which tries to preserve the manifold structure of targets. The proposed target detector termed as MSP tries to separate tar-

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