Optics & Laser Technology 57 (2014) 284–292

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Spatio-contextual fuzzy clustering with Markov random field model for change detection in remotely sensed images

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A R T I C L E I N F O

Available online 30 October 2013

Keywords:
Change detection
Markov Random Field
Multitemporal images

A B S T R A C T

This paper presents a novel spatio-contextual fuzzy clustering algorithm for unsupervised change detection from multispectral and multitemporal remote sensing images. The proposed technique uses fuzzy Gibbs Markov Random Field (GMRF) to model the spatial gray level attributes of the multispectral difference image. The change detection problem is solved using the maximum a posteriori probability (MAP) estimation principle. The MAP estimator of the fuzzy GMRF modeled difference image is found to be exponential in nature. Convergence of conventional fuzzy clustering based search criterion is more likely to lead the clustering solutions to be getting trapped in a local minimum. Hence we adhered to the variable neighborhood searching (VNS) based global convergence criterion for iterative estimation of the fuzzy GMRF parameters. Experiments are carried out on different multispectral and multitemporal remote sensing images. Results confirm the effectiveness of the proposed technique. It is also noticed that the proposed scheme provides better results with less misclassification error as compared to the existing techniques. The computational time taken by the proposed technique is comparable with that of the HTNN scheme.

1. Introduction

Detection of land-cover changes from multitemporal remote sensing images is a challenging task. Unsupervised change detection from a pair of multitemporal and multispectral remote sensing images is widely used and plays an important role in many application domains. These include environmental monitoring [1], assessment of land cover dynamics [2], forest monitoring [3], and urban studies [4], etc.

The most widely used change detection scheme includes three fundamental steps: preprocessing, comparison (or difference image generation) and analysis [5]. The preprocessing stage includes normalization of the available multitemporal remote sensing images (i.e., co-registration, radiometric correction, geometric correction, atmospheric correction, etc. [6]), so that they can be used in the subsequent stages. In the comparison step, the multispectral remotely sensed images taken over the same geographical area at different times are compared using suitable mathematical operators like single band differencing, vector differencing, ratios, etc. [7]. The change detection map is achieved in the analysis step, by labeling the pixels of the difference image into changed and unchanged classes.

Two kinds of popular approaches can be found in the pattern recognition [8] literature to label the pixels of the difference images into changed and unchanged classes: the supervised [9] and the unsupervised approaches [10,11]. The supervised approach needs ground reference information for setting up the system parameters, whereas the unsupervised approach does not. Although supervised approaches result in higher change detection accuracies, unsupervised techniques are more popular as the ground truth information is not available in many change detection applications.

The use of unsupervised approaches for change detection is well documented in the literature [6]. Among them, the most widely used are pixel-based crisp thresholding techniques for the analysis of the difference image [12]. An unsupervised change detection technique has been studied by Bovolo et al. in [13]. Here the authors present a change detection approach that jointly analyzes the spectral channels of multitemporal images in the original feature space. This is accomplished by a semi-supervised support vector machine, where a Bayesian thresholding scheme is exploited for deriving an initial "pseudo" training set. Recently, the authors also proposed an unsupervised change detection technique based on Change Vector Analysis (CVA) and support vector domain description schemes [10]. This approach formulates the change detection problem as a minimum enclosing ball (MEB) problem with changed pixels as target objects. All the above-mentioned techniques are pixel based and do not take into account the spatial context information [14].

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0030-3992/$ - see front matter
http://dx.doi.org/10.1016/j.optlastec.2013.10.003

A spatio-contextual change detection scheme is reported in [5], where Hopfield-type neural network (HTNN) is used to detect the changed region corresponding to multitemporal remote sensing images. It is found that HTNN updates the output status of the neurons until a minimum of the energy function is reached. In order to improve pixel-based crisp results, several approaches have been proposed in the literature that try to model the fuzzy and the spatio-contextual information present in the difference image. In this regard, an analysis of the effectiveness of fuzzy clustering in change detection problems can be found in [15]. In [12] authors show a spatial-context based approach to change detection which takes advantage of the Markov Random Field (MRF) theory for spatial-context modeling.

On the basis of the above-mentioned analysis, to the best of our knowledge in the literature no method is available that simultaneously takes advantage of the benefits of both fuzzy clustering, variable neighborhood searching (VNS) and spatio-contextual approaches to change detection. It may be noted that the MAP estimate of the GMRF used to model the multispectral multitemporal difference image is exponential in nature. In the literature different searching techniques are used to asses a better change detection map. To overcome the difficulty of being stuck to local minima, VNS heuristic is embedded in the MRF-fuzzy clustering framework. The main objective of this work is to present a robust technique considering the advantages of the techniques like MRF model in the fuzzy clustering framework and variable neighborhood searching for remotely sensed image analysis.

In this paper, we propose a spatially constrained unsupervised fuzzy clustering approach for detecting changes from the multispectral and multitemporal remote sensing images. In greater detail, the proposed method uses fuzzy statistics and GMRF model to model the gray level attributes of the multispectral difference image (generated from the two co-registered and radiometrically corrected multispectral band images acquired over the same geographical area at two different instants of time). The MAP or the solutions obtained by conventional fuzzy c-mean (FCM) clustering based convergence criterion depends on choice of the initial cluster centers (chosen randomly) and more likely to stuck to a local minimum. Thus in the proposed scheme we have used a VNS based global convergence criterion for iterative estimation of the fuzzy GMRF parameters.

Experiments are carried out with three sets of multispectral and multitemporal remote sensing images. To assess the effectiveness of the proposed technique, the results obtained by the proposed scheme are compared with those of (i) the manual trial-and-error technique, (ii) the context sensitive change detection scheme based on Hopfield-type neural network [5], and (iii) the MRF-fuzzy C-means scheme. Experimental results point out that the proposed scheme provides change detection maps with a smaller change detection error than other methods used in the comparison.

The organization of this paper is as follows. Section 2 presents an overview of the proposed technique and describes the proposed scheme in detail. The data set used in the experiments and the corresponding change detection results are analyzed in Section 3. Finally, Section 4 draws the conclusions of this work.

2. Proposed fuzzy context sensitive method

The proposed method takes advantage of three main methodologies: (i) MRF model; (ii) spatio-contextual FCM (fuzzy C-means) clustering; and (iii) VNS based optimization algorithm.

Let y_1 and y_2 be two co-registered and radiometrically corrected γ-spectral band images of size $M \times N$, acquired over the same geographical area (with same sensors and same angle of view) at two times T_1 and T_2, and let $\omega = \{\omega_{ch}, \omega_{un}\}$ be the set of classes of changed and unchanged pixels to be distinguished, respectively. In the first step of processing, a γ-band multispectral difference image is generated by subtracting the vector of corresponding pixels in y_1 and y_2. To cluster the difference image into changed and unchanged classes, we propose to model it with a fuzzy-statistics based MRF scheme. The adaptive neighborhood searching based convergence algorithm is used as maximum a posterior probability (MAP) estimator. The Expectation Maximization (EM) algorithm is exploited to estimate the parameters of the MRF model. The block diagram of the proposed method is given in Fig. 1.

In this section, we describe the MRF-MAP framework and different spatio-contextual fuzzy clustering schemes, which are the basis of the proposed approach.

2.1. Markov random field model

MRF model has been used for image segmentation and classification from the last three decades [16–22]. It is a spatio-contextual statistical modeling based segmentation scheme that partitions an image into different clusters with the constraint of Gibbs distribution as prior gray level distribution. In MRF-based change detection, usually the magnitude y of the γ-band multispectral difference image is considered and is assumed to be a spatio-contextual entity. Each pixel in y is assumed as a site s denoted by y_s, $s \in S$, where $S = M \times N$ represents the set of sites. Y represents a random field and y is a realization of it. Let X be a random variable and the realization of $X{=}x$ be a partition of the image into 2 region types, i.e., $x \in \omega$ is a generic set of labels assigned to the pixels in y. Classes can appear spatially disjoint in the image.

The realization x cannot be obtained deterministically from y. Hence, $\hat{x}$ should be estimated from y. One way to estimate $\hat{x}$ is based on the MAP criterion, which yields the $\hat{x}$ value that

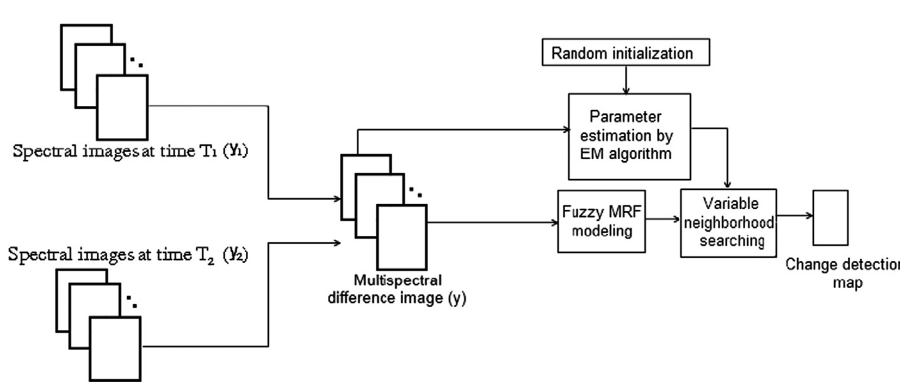

Fig. 1. Diagram of the proposed change detection scheme.