EDGE-PRESERVING CLASSIFICATION OF HIGH-RESOLUTION REMOTE-SENSING IMAGES BY MARKOVIAN DATA FUSION

Gabriele Moser and Sebastiano B. Serpico

University of Genoa, Dept. of Biophysical and Electronic Eng. (DIBE), via Opera Pia 11a, I-16145 Genoa (Italy), e-mail: sebastiano.serpico@unige.it

1. EXTENDED ABSTRACT

Current and future Earth-observation missions allow images of the Earth surface to be acquired up to very high spatial resolutions. Specifically, 1-5 m (or lower) resolution spaceborne sensors, such as IKONOS, QuickBird, Orbview, SPOT-5, COSMO/SkyMed, or TerraSAR have become available. The resulting very high spatial resolution (HR) images provide hugely detailed information about the Earth surface for applications such as urban area monitoring, precision farming, or damage assessment after environmental disasters. However, the extraction of land-use or land-cover information from such images is a difficult problem, due to the intrinsic complexity of the observed scene.

Indeed, as compared to coarser-resolution images, the ground materials in the scene can be much better observed in multispectral HR imagery. They may include concrete, asphalt, metal, plastic, glass, water, grass, trees, shrubs, and bare soil, to list just a few. They can be arranged into very complex spatial-geometrical configurations in the image. This gives rise to more critical problems for image classification. Indeed, the finer the resolution, the larger the number of subclasses based on the spatial distribution of material responses ("material subclasses"), which affect the capability to accurately discriminate the thematic (user-defined) classes [1, 2]. Due to these spatial heterogeneity issues, supervised classification techniques developed for coarser-resolution images are expected not to be effective when applied to HR data.

In this paper, a novel supervised classification technique is proposed for multispectral HR images. The method is based on the key-idea to jointly model by a novel Markovian data-fusion approach the "material subclasses" in the image (detected through a hierarchical clustering algorithm), the thematic classes (via training data), and the edges between distinct thematic classes (modeled by line processes). Markov random fields (MRFs) are a wide class of probabilistic models that allow both contextual information [3] and further information sources [4] to be integrated in an image-classification task by formulating the "maximum *a-posteriori*" (MAP) decision rule as the minimization of a suitable "energy" function. MRFs have been applied by the remote-sensing community in many applications, such as classification of multisensor, multitemporal, and hyperspectral data, segmentation, texture analysis, denoising, and change detection [1, 2, 3, 4].

Given a multispectral HR image and a corresponding training map, which characterizes the thematic classes in the image, the proposed method generalizes the MRF-based technique proposed in [1] by extending the related MRF model through an edge-preserving approach and by endowing the resulting model with a novel parameter-optimization technique. The algorithm in [1] models each thematic class as a collection of different "material subclasses" that are automatically identified by using the hierarchical clustering method proposed in [5]. This clustering algorithm, which is based on a maximum-entropy statistical-thermodynamical model for the image [5], is used because it can generate a complete hierarchy of clustering maps to different degrees of spatial detail and because it was already found in [6] to accurately identify the material subclasses in HR imagery. A hybrid supervised/unsupervised MRF model was introduced in [1] to fuse the information conveyed by the hierarchical clustering result and the thematic-class information represented by the training data.

The technique proposed in the present paper introduces a novel MRF model that extends by using line processes the model in [1]. Given an MRF defined on a given pixel lattice, a line process is a dual contextual model formalizing the possible presence of edges between adjacent pixels [3]. In order to integrate such edges in the Markovian formulation, a collection of allowed geometrical configurations can be defined for the edges and different potential functions may be introduced to characterize the probability distribution of these configurations. As a consequence, the resulting two-dimensional stochastic process is characterized by an energy contribution [3]. Here, we integrate this energy contribution into the formulation

developed in [1] in order to define an edge-preserving hybrid supervised/unsupervised MRF model for HR image classification.

According to the Markovian approach to data fusion [4], the energy function of the proposed model is expressed as a linear combination of three components, related to the pixelwise probability distribution of the multispectral channels (modeled according to the usually accepted multivariate Gaussian model [7]), to the spatial-contextual information associated with material subclasses and thematic classes (modeled thanks to the aforementioned hierarchical clustering), and to the line process representing the edges, respectively. The task of the energy minimization is addressed by the "iterated conditional mode" (ICM) approach that is well known as a good tradeoff between the accuracy of the resulting classification map and the related computational burden [4]. ICM is an iterative procedure that converges to a local minimum of the energy function [4]. In the case of the proposed MRF model, that jointly takes into account both class and edge information, the result obtained at the convergence of ICM is actually a set of two maps representing a thematic classification and an edge-detection map, respectively. In order to initialize ICM, a noncontextual classification result (generated by the simple Gaussian MAP classifier [7]) is used to provide an initial map of thematic class labels, and the well-known Canny algorithm is utilized to generate an initial map of the edges [8].

A hybrid supervised/unsupervised approach is also developed to address the problem of optimizing the parameters of the proposed MRF model, i.e., the weights of the linear combination of the aforementioned energy components. The method developed in [9] is used to optimize the parameters of the spectral and spatial energy terms. This method is supervised and exploits training data to define a system of linear inequalities that are related to the correct classification of the training pixels and are solved by the Ho-Kashyap numerical procedure [10]. However, no training information is available, in general, for the edges in the image, which makes the approach in [9] unfeasible for the optimization of the weight parameter of the line-process energy term. In order to accomplish this optimization task, an unsupervised method is developed that is based on the Besag's pseudo-likelihood algorithm [11]. The method numerically maximizes a pseudo-likelihood function related to the MRF-based joint distribution of the material classes and edges in the image, and is combined with the aforementioned supervised approach in [9].

The proposed technique is tested on a multispectral IKONOS image acquired over Itaipu (Brazil/Paraguay border). The results are assessed both quantitatively (by means of confusion matrices computed over test samples) and qualitatively (by means of visual photo-interpretation). Very accurate classification maps have been obtained, pointing out a large accuracy improvement as compared both to noncontextual classification techniques and also to the previous contextual method in [1]. This suggests the effectiveness of the proposed method in exploiting the information conveyed by material and thematic classes and by the edges in the image. The classification results have also proved robust to the initialization phase, specifically exhibiting only small variations even when strongly modifying the initial edge map. We also note that, as a by-product of the classification process, an edge map is obtained at the convergence of the method. A visual analysis confirmed the accuracy of this result as well, thus suggesting the capability of the proposed approach to jointly map the class and edge information in the image through Markovian data fusion.

11. REFERENCES

[1] F. Causa, G. Moser, S. B. Serpico, "A novel MRF model for the detection of urban areas in optical high spatial resolution images," AIT Italian Journal of Remote Sensing, 38, 2007.

[2] G. Moser, S. B. Serpico, "Classification of high-resolution images based on MRF fusion and multiscale segmentation", Proc. of IGARSS-2008, July 6-11, 2008, Boston (USA).

[3] S. Geman, D. Geman, "Stochastic relaxation, Gibbs distributions, and the Bayesian restoration," IEEE Trans. Pattern Anal. Machine Intell., 6:721-741, 1984.

[4] A. H. S. Solberg, T. Taxt, A. K. Jain, "A Markov random field model for classification of multisource satellite imagery," IEEE Trans. Geosci. Remote Sensing, 34:100-113, 1996.

[5] Y. Wong, E. Posner, "New clustering algorithm applicable to multispectral and polarimetric SAR images", IEEE Trans. Geosci. Remote Sensing, vol. 31, no. 3, pp. 634–644, 1993.

[6] M. De Martino, G. Macchiavello, S. B. Serpico, "Partially supervised classification of optical high spatial resolution images in urban environment using spectral and textural information", Proc. of IGARSS-2004, 20-24 September 2004, Anchorage (USA), vol. 1, pp. 77-80.

[7] D. Landgrebe, "Signal theory methods in multispectral remote sensing", John Wiley and Sons, 2003.

[8] W. K. Pratt, "Digital image processing", Wiley, 1991.

[9] S. B. Serpico, G. Moser, "Weight parameter optimization by the Ho–Kashyap algorithm in MRF models for supervised image classification," IEEE Trans. Geosci. Remote Sensing, 44:3695-3705, 2006.

[10] R. O. Duda, P. E. Hart, D. G. Stork, Pattern classification, Wiley, 2001.

[11] J. Besag, "On the statistical analysis of dirty pictures", J. R. Stat. Soc., B, vol.48, no.3, pp. 259-302, 1986.