UNSUPERVISED CHANGE DETECTION WITH VERY HIGH-RESOLUTION SAR IMAGES BY MULTISCALE ANALYSIS AND MARKOV RANDOM FIELDS

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1. EXTENDED ABSTRACT

Change-detection methods represent important remote-sensing image-analysis tools in applications such as environmental monitoring and disaster management. In particular, the technical contribution of remote sensing to environmental risk prevention and management in the context of disasters such as fires, earthquakes, floods, etc., heavily relies on the availability of very high resolution (VHR), all-weather, day/night, and short revisit time data. In this perspective, multitemporal synthetic aperture radar (SAR) conveys a great potential, thanks to its capability to collect data irrespective of Sun-illumination and with a very limited sensitivity to atmospheric conditions. This potential is further enforced by current satellite SAR missions, such as COSMO/SkyMed or TerraSAR-X, that allow very high resolution (around 1 m) data to be collected with very short revisit times (up to 12 h) [1]. However, powerful processing techniques aimed at detecting ground changes from multitemporal observations acquired by such novel VHR satellite sensors are needed in order to effectively exploit this potential.

In the present paper, a novel multiscale contextual method is proposed to address the problem of change detection with VHR SAR in a completely unsupervised framework, i.e., by assuming no ground-truth information to be available for training purposes at any observation date. The method extends to VHR SAR the techniques developed in [2] and [3] for unsupervised multiscale change detection with medium-resolution optical images. Specifically, in order to generate accurate change maps from VHR

SAR amplitude images, a multiscale approach is used, in which transformed features related to different spatial observation scales are extracted and jointly used. Features at finer scales are likely to highlight many geometrical details, but also to be severely affected by speckle, whereas features at coarser scales allow less precise geometrical details to be appreciated, but also exhibit a stronger immunity to speckle. In this perspective, a multiscale approach, exploiting the information at coarser scales to globally identify changed areas and the information at finer scales to improve the accuracy of detection of the details, may represent effective choices. Specifically, the method adopts an image-ratioing strategy, which is a usual choice for unsupervised change detection with SAR imagery [4, 5], and applies a dyadic wavelet decomposition to the corresponding logarithmic ratio image, by discarding the resulting high-pass components in order to generate a set of progressively coarser-scale features. In particular, since noise contribution in a SAR amplitude ratio image is multiplicative [4, 5], wavelet operators, which are linear, are expected to be more effective when used with such a logarithmic homomorphic filtering strategy [6] than when directly applied to the ratio data.

Then, an MRF-based approach is adopted to fuse the information conveyed by the resulting multiscale data-set. MRFs are a general family of stochastic image models that allow both spatial-contextual information and further possible information sources to be integrated into Bayesian image-analysis schemes, through the minimization of suitable "energy functions" [7]. Successful applications of MRF-based modeling has been used in remote-sensing for classification, change-detection, denoising, and feature extraction (an overview can be found in [8]). Here, a novel MRF model is proposed by generalizing to change detection with VHR SAR the MRF model introduced in [3] in the framework of multiscale change detection with optical images. According to the Markovian approach to data fusion [7], the energy function that characterizes the proposed MRF model is expressed as a linear combination of distinct energy contributions, each formalizing the information conveyed either by the spatial context or by each extracted multiscale feature. Specifically, the latter energy contribution is analytically expressed in terms of a parametric model for the statistics of the pixel intensities in the feature extracted at the corresponding scale, when conditioned to either the "change" or "no-change" class. Nakagami-ratio, Weibull-ratio, and log-normal parametric families have recently been derived as analytical models for the statistics of SAR amplitude ratios in change detection applications, and have also been found to accurately model the statistics of the ratios of speckle-filtered SAR data [5]. In this paper, these parametric families are generalized to the problem of modeling the class-conditional statistics of the extracted multiscale features and consequently integrated in the proposed Markovian multiscale fusion framework.

The proposed MRF model exhibits several internal parameters, either included in the above-mentioned class-conditional parametric distributions, or representing weight parameters, which tune the reciprocal role of the contextual and multiscale energy contributions in the energy function. Similar to the approach introduced in [9] for change detection with single-scale multichannel SAR, we combine the expectation-maximization (EM) algorithm and the method of log-cumulants (MoLC) in order to jointly address the tasks of model-parameter estimation and energy minimization. EM is a well-known parameter-estimation algorithm dealing with problems of data incompleteness and converging, under mild assumptions, at least to a local maximum of the log-likelihood function [10]. MoLC is a recent parameter-estimation algorithm, developed in the framework of SAR data analysis and based on the idea of exploiting the theory of Mellin transforms to state a system of nonlinear equations relating the unknown parameters of a given parametric distribution to a suitable set of logarithmic moments and cumulants [11]. MoLC estimates have been proved to exhibit very good analytical properties and have obtained high estimation accuracies in the applications to many SAR-specific parametric families, including the above-mentioned Nakagami-ratio, Weibull-ratio, and log-normal [5].

Specifically, since the application of EM-like procedures to MRF models is typically time-expensive, the so-called "mode-field" EM approximation is used, which usually represents an effective tradeoff between parameter-estimation accuracy and computational burden [12]. Furthermore, since EM provides no closed-form solution when applied to the Nakagami-ratio or Weibull-ratio parametric families [9], a novel integrated formulation of the mode-field-approximated EM with MoLC is developed to automatically estimate the parameters of the proposed multiscale MRF model. The resulting method is iterative, it is initialized with a preliminary change-detection result generated on a single-scale basis (e.g., by the generalized Kittler and Illingworth unsupervised algorithm proposed in [5]), and jointly updates, at each iteration, both the estimates of the MRF model parameter and the change map. Convergence is analytically ensured thanks to the well-known convergence properties of EM-like techniques [10].

The proposed method has been tested with two distinct COSMO/SkyMed data sets, involving both stripmap (2.5-m spatial resolution) and spotlight (1-m spatial resolution) images acquired in 2009 over Alessandria and L'Aquila (Italy), respectively. Ground changes are present in both multitemporal data sets, due to a flood and a severe earthquake that occurred in the Alessandria and L'Aquila areas, respectively. Accurate and promising experimental results have been obtained by the proposed method with both data sets. A thorough assessment of these results, involving both a visual qualitative analysis of the corresponding change maps and a quantitative analysis, based on the computation of false-alarm rates, change detection accuracies, and overall error rates with respect to ground-truth reference data (when available), will be included in the full paper. The results will also be compared with those given by previous change-detection techniques proposed in the SAR literature and the behaviors of the proposed method as a function of the number of extracted scales and of the adopted wavelet operator will also be experimentally discussed.

2. REFERENCES

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