A CONCEPTUAL FRAMEWORK FOR CHANGE DETECTION IN VERY HIGH RESOLUTION REMOTE SENSING IMAGES

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1. INTRODUCTION

The ever increasing availability of remote sensing images regularly acquired by satellites over the same geographical area makes the analysis of multitemporal data (and the related applications) one of the most interesting research topics for the remote sensing community. In the last decade, a new generation of satellite sensors has been operated, which can acquire panchromatic (PAN) and/or multispectral (MS) images with submetric and metric resolution. Among these satellites, we recall WorldView-1 and -2, Ikonos, Eros, Quickbird, SPOT-5, *etc*. From 2007, it is also possible to acquire synthetic aperture radar (SAR) images with resolution up to 1m, thanks to the Cosmo-Skymed and TerraSAR-X missions. From a theoretical perspective, very high resolution (VHR) multitemporal images represent a valuable and rich information source for performing the detection of changes occurred on the Earth surface at different scales [1]-[3]. Nonetheless, the huge amount of data acquired from the satellite sensors requires the definition of automatic change-detection algorithms that can extract the change information without relying on the manual processing of experts and the availability of ground truth information. Although this type of algorithms is almost mature for the analysis of medium and high resolution multitemporal images, at the present the situation is drastically different when VHR images are considered [2].

Unsupervised change-detection techniques generally compare two images acquired on the same geographical area at different times by assuming that they are similar to each other except for the presence of changes occurred on the ground. Unfortunately, this assumption is seldom satisfied, especially when VHR MS/PAN images are considered [1]. This is due to both the complexity of the objects present in the scene (which may show different spectral signatures at two different dates even if their semantic meaning does not change) and to differences in the acquisition conditions (e.g., atmospheric and sunlight conditions, sensor acquisition geometry, etc.). These factors involve a dramatic effect on images taken at sub-metric resolution. In order to satisfy the similarity assumption, pre-processing steps are required, including: image co-registration, radiometric and geometric corrections, and noise reduction. However, in practice, it is not possible to obtain a perfect matching between multitemporal VHR images. This may significantly affect the accuracy of the change-detection process.

This paper addresses the main problems and critical issues associated with the development of automatic and unsupervised change-detection techniques for VHR images. After a critical analysis of the literature and of the main open issues associated with unsupervised change-detection methods, a general conceptual framework for addressing this type of problems is proposed. Experimental results are presented which point out the effectiveness of the proposed framework.

2. METHODOLOGY

The high complexity of VHR images mainly depends on two sets of factors: i) the intrinsic complexity, spectral non homogeneity and multiscale properties of the objects modeled in VHR images; and ii) possible different acquisition conditions of multitemporal VHR images. The first set of factors is associated with the complexity of the objects imaged with metric or submetric resolution. Objects that are considered homogeneous from a semantic viewpoint (e.g. buildings) have often spectral signatures that at high resolution result inhomogeneous due to the different sub-objects from which they are composed (e.g., a building roof may be made up of different pitches, vegetation, chimneys, etc.). This is critical for both classification and change-detection applications based on VHR images and should be managed taking in to account the multiscale properties of the objects. The second set of factors is very important because it makes it complex a proper comparison between multitemporal data. Different sensor view angles imply differences in the acquisition geometry and in shadows resulting in significantly different object footprints on the acquired images. In addition, differences due to seasonal effects, different illumination conditions result in different spectral signatures when optical images are considered.

All the aforementioned issues, when projected on the comparison of multitemporal images, involve two possible types of changes between images: i) radiometric changes; and ii) semantic changes. In this paper, we define radiometric changes as statistically significant changes between the radiance of corresponding pixels (or objects) in two images acquired at different times. Semantic changes are changes occurred on the ground between the acquisition of the two considered images, which are relevant for the considered application. Usually semantic changes are associated with radiometric changes (if the appropriate sensor is used for monitoring the phenomenon under investigation), whereas radiometric changes do not necessarily imply semantic changes. It follows that standard change-detection approaches, which are based on the identification of radiometric changes, result in a high false-alarm rate. This is very critical for the effects on the change-detection accuracy, which decreases significantly.

For properly taking into account the semantic behavior of changes, it is fundamental to include in the unsupervised change-detection techniques a semantic level at which image comparison can be performed at a conceptual level higher than that of the pure pixels (or of simple objects) only modeled by their radiometric properties. This requires additional steps for the extraction of the semantic information. Two different (but not competitive) strategies can be adopted to this purpose: i) detection of radiometric changes due to different acquisition conditions (e.g. residual registration noise, different shadows, *etc*.) and thus not related to semantic changes; and ii) extraction of the semantic meaning of the changed pixels (or better, objects). Such definition of the problem results in the need of defining multilevel change-detection approaches, which try to model the different sources of radiometric changes present in the data at different resolution and conceptual levels. This allows one to simplify the distinction between real changes and source of errors. If proper implemented, this approach is suitable to reduce the limitations of standard change-detection techniques in modeling: i) the residual misregistration (registration noise) among multitemporal images, ii) the high spatial correlation between pixels in a neighborhoods, and iii) the intrinsic multiscale nature of objects present in VHR images.

From a conceptual viewpoint, the extraction of information from the images can be obtained by extracting meta-levels that are focused on the semantic meaning of the objects rather than on radiometric differences. In other words, original images should be “simplified” reducing the high variability that characterizes the radiometry at pixel level. This can be done according to different strategies that can reach different tradeoffs between simplification and fidelity to the radiometric content of the original images. In this framework, classification can be seen as the highest simplification of each images, which transforms the image into the semantic information modeled by the information classes recognized by the classification algorithm. It is worth noting that although information classes arise from radiometric information, they do not include information about radiometry. However, supervised classification requires the availability of multitemporal reference data (if complex domain adaptation strategies are not considered), thus resulting not feasible in many applications where a priori information about land covers is not available. Therefore alternative unsupervised techniques should be used for image simplification (e.g. morphological filters [4], attribute filters [5], specific feature/object detection algorithms [7], *etc*.) in order to achieve reliable results with limited prior information. It is worth noting that for a proper modeling of the semantic meaning of the investigated changes some prior conceptual information is always necessary.

Each simplification step leads to the definition of a meta-level (which could be represented either in a raster or vectorial form) at which it is possible to perform change detection. If properly defined, meta-levels allows us to effectively represent different radiometric effects (semantic changes, shadows differences, seasonal changes, *etc*.). Thus, a proper fusion of different meta-level maps/images can result in a change detection map in which semantic changes can be isolated from source of noise.

This framework is intrinsically suitable to the analysis of multisensor multitemporal images. In this case, the common base of comparison of images acquired by different sensors is the meta-level, which should represent the same kind of information in the same geographical reference system. Whenever this constraint is satisfied, the approach adopted for the simplification of the original images can be sensor dependent and also very different for different kinds of images (e.g., building detection in VHR SAR [6] and multispectral images [7]). It is worth noting that when SAR and multispectral images are considered proper transformation should be applied for obtaining compatible geometric representations of the scene in a common reference system. These concepts and the proposed framework will be presented in greater detail in the full paper.

3. EXPERIMENTAL RESULTS AND CONCLUSION

The framework presented in this paper will be illustrated with different examples related to the analysis of both multispectral and SAR VHR multitemporal images. First, the effects of different acquisition angles on the change detection, as well as of different shadows and radiometric distortions are pointed out by using standard change-detection techniques. Second, the application of the proposed approach is illustrated by considering the use of different strategies for extracting the meta-level information, both in MS and SAR images. Also procedures for extracting radiometric changes associated with source of noise (i.e., residual misregistration [1],[2] and different shadow extensions) are integrated in the experimental analysis with the proposed system. The attention will be focused on the problem of detection of changes in buildings by considering both multitemporal and multispectral Quickbird images and the integration of multispectral and SAR images. Results show that the proposed framework is effective for properly addressing complex change-detection problems by using multitemporal VHR images. Results also confirm the flexibility of the proposed framework with respect to different problems and different kinds of VHR sensors.

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