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A novel edge-weight based fuzzy clustering method for change detection in SAR images

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ABSTRACT

Change detection has found wide application in several fields, and in this paper we put forward a novel change-detection approach in synthetic aperture radar (SAR) images. The approach is implemented to the difference image (DI) through the modification of conventional fuzzy c-means (FCM) clustering method. In order to reduce the impact of speckle noise, the objective function is modified by introducing piecewise prior, which serves as the use of local spatial information. The approach mainly includes an edge pre-estimation step and an objective function optimization step. In the first step, the areas containing the edges in the DI is detected by the level set method, in which an energy functional is established to find out the final level set function. Then a weight which serves as a smooth parameter in the second step is output according to the computed level set function. In the second step, the objective function is optimized by the modified accelerated proximal gradient (APG) algorithm, in which the Lagrange multiplier method is applied to determine some other unknown variables. Our contribution lies in two aspects. Firstly, the approach is capable of reducing the impact of speckle noise in the homogeneous region and preserving blurred edges due to the edge pre-estimation step along with its output weight. Secondly, the approach converges in a fast speed because of the use of the APG algorithm that super-linearly converges. Theoretical analysis and experimental results on simulated and real SAR datasets show that the proposed approach is able to detect the real changes by reaching a trade-off between noise reduction and edge preservation. The results also demonstrate its fast convergence speed.

1. Introduction

Change detection (CD) [23,25,33,35] is the process that identifies changes occurred between two (or more) images based on the image properties. Such an analysis is called unsupervised when it aims at discriminating between two opposite classes (referred to as the unchanged and changed classes) without any prior knowledge about the scene (i.e., no ground truth is available for modeling the classes). It is an important issue because of its wide applications in several fields such as remote sensing [4,8,20,27,32], medical diagnosis [3,12,30,31] and video surveillance [18,36]. Recently, there has been an increasing awareness of the issue due to the frequent occurrence of catastrophes such as hurricanes, earthquakes and floods. An efficient and effective CD task after a catalyst appears vital and urgent when lives and properties are at stake. The

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images by synthetic aperture radar (SAR), which has the main advantage to be able to operate in all-weather condition [28], can serve as indispensable sources of CD because of their advantages over optical images that are quite dependent on atmospheric and sunlight conditions.

The pivotal steps in the CD task can be concluded as three steps: (1) Image preprocessing, (2) generation of a difference image (DI) from multitemporal images, and (3) analysis of the DI. The first step usually includes geometric correction and registration, aimed at aligning two images into the same coordinate frame, and sometimes it is also necessary that the images be filtered in this step. In the second step, a DI is generated, a process to discern the unchanged area and changed area initially. Changes are usually detected based on the generated DI through binary classification in the third step. It is worth noting that the term “difference image” means the image to show the basic differences between the two original images.

For example, in [16], an extension of the spatial NL-means filter is used to preprocess the SAR images and then the Rayleigh Kullback Leibler measure is used to detect the changes. In [19], the authors incorporate a filtering step by a non-local approach and a spatially varying equivalent number of looks.

Notwithstanding the advantages of SAR images, how to cope with speckle noise present in them is one of the most difficult problems [10,14]. Since the speckle noise is basically multiplicative, the log-ratio operator is usually utilized to generate a DI, which declines the impact of the speckle noise initially. Nevertheless, a further study of the analysis in the third step is still essential.

The aim of the third step is to divide the DI into the two classes. In general, as we view the CD task as an image binary segmentation problem, fuzzy c-means clustering (FCM) methods are proven to be efficient and flexible [11,26,34]. FCM algorithm is sensitive to noise in the CD task since it does not take any spatial information into consideration, and i.e. every pixel in the DI is individual and the information provided by its neighborhood (often referred to as the local spatial information) is overlooked. In the case of SAR images characterized by speckle noise, the use of it is of great significance when we consider the noise reduction. In general, the corruption of speckle noise lies in two aspects: in homogeneous regions as the noise points and in heterogeneous regions as the blurred edges. In many literatures, researchers have endeavored to exploit such information, and it is usually done through the modification of the objective function or the membership. In [5], Cai et al. proposed the fast generalized FCM algorithm (FGFCM) for image segmentation by incorporating the spatial information and the intensity of the local pixel neighborhood as well as the number of grey levels in an image. FGFCM is capable of reducing the execution time by clustering on grey-level histogram rather than on pixels significantly with less sensitivity to noise to some extent. In [21], Krindis and Chatzis proposed a robust fuzzy local information C-means clustering algorithm (FLICM) for image segmentation. The new characteristic of FLICM is the use of a fuzzy local similarity measure which is aimed at guaranteeing noise insensitiveness and image detail preservation. In particular, a novel fuzzy factor with no artificial parameter is introduced into its objective function, enhancing the clustering performance. The method referred to as the reformulated FLICM (RFLICM) in [15] is an improvement of FLICM, aiming to undertake the analysis of CD better. In RFLICM, by adding a new fuzzy factor into its objective function, the impact of speckle noise is further reduced. FLICM can also be modified by introducing a kernel which utilizes non-Euclidean distance and serves as a trade-off weighted fuzzy factor, as is described in [13] and referred to as the kernel weighted FLICM algorithm. This modified method does generate some excellent results when we consider the segmentation of say natural images and medical images. In addition, Markov random field (MRF) [37] is also an opportune tool to introduce the local spatial information, and in [9] Chatzis and Varvarigou proposed a novel fuzzy objective function regularized by Kullback–Leibler divergence information. Their algorithm is facilitated by the application of a mean-field-like approximation of the MRF prior. Following the work done in [9], we proposed a novel MRF energy function in which the mutual relationship among pixels in a neighbor system is further considered [14], and the approach also involves the use of the least square method.

Unlike the methods mentioned above, another way to improve the performance of FCM is introducing piecewise smooth prior. As far as the literatures are concerned, it is first introduced to FCM by He *et al.* [17]. They proposed a total variation FCM (TV_FCM) algorithm in which the objective function is regularized by adding a TV functional. There are two major drawbacks of TV_FCM: (1) the fuzzifier is limited to be set as 1 but it is conventionally set as 2 to ensure strict convexity of the objective function; and (2) it applies piecewise smooth prior uniformly on the whole image domain, and that is, preserving edges is not handled. In this paper, we propose a novel approach which includes an edge pre-estimation process and hence the name the edge-weight based FCM (EW_FCM) method. EW_FCM smartly applies piecewise smooth prior in the image domain, and that is, weak smooth force on the areas that possibly contain true edges and strong smooth force on the areas that less possibly contain true edges.

- Firstly, the EW_FCM method finds out the areas that possibly contain true edge by minimizing a new energy functional through level set method. Compared with the traditional level set methods, e.g., geodesic active contours [6], the proposed procedure converges fast and does not require a re-initialization procedure.
- Secondly, the EW_FCM method applies the piecewise smooth prior to FCM. Comparing with TV_FCM, the proposed method does not limit the setting of fuzzifier and does not apply piecewise smooth prior uniformly on the whole image domain. Hence, it can not only filter out the impacts of speckle noises, but also preserve weak edges.
- Finally, the accelerated proximal gradient (APG) [1] algorithm is modified to minimize the objective function of EW_FCM. Since the original APG algorithm is designed for minimizing function of single variable and the proposed objective func-