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Cooperation of the partial differential equation methods and the wavelet transform for the segmentation of multivalued images

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Abstract

In this work, the wavelet transform (WT) and two partial differential equations (PDEs)-based segmentation methods are merged together towards an efficient segmentation paradigm that integrates level-set functions and wavelet-based singularity detection to object extraction from multivalued images. To this end, different interfaces of the image regions are characterized using a wavelet-based multiscale multistructure tensor that is capable of identifying edges in spite of the presence of noise. With this wavelet-based multistructure tensor, the edge structures of a vector-valued image can be studied at different scales. This multiresolution edge-detection approach allows to reconstruct the accumulated orientational information of the multispectral image. Detected edges are then modeled by level-set functions. A functional is defined on these level sets whose minimizers define the optimal classification of objects. In a second step, the cooperation of PDE and WT is used for pioneering active contour segmentation method. For that purpose, foveal wavelets [S. Mallat, Foveal orthonormal wavelets for singularities, Technical Report, Ecole Polytechnique, 2000], known by their high capability to precisely characterize the hölder regularity of singularities, are used to detect the image contours. These wavelets are capable of accurately characterizing edges of noisy images. The obtained foveal coefficients are used to guide the curve flow in an active contour segmentation process. Therefore a foveal-wavelet-based snake approach is formulated. The proposed approach is capable of driving the snake curve to the real edges of different regions in a noisy image. Promising experimental results illustrate the potential of the cooperation of the PDE and the WT in the segmentation of multivalued images.

Keywords: Partial differential equations; Wavelet; Segmentation; Color images

1. Introduction

Starting with Osher and Sethian's pioneering work [17], level-set methods have become a fundamental tool in image processing, computer vision and computer graphics [15,16,21]. They make use of a number of interesting partial differential equations (PDEs) including mean curvature motion [1], self-snakes [20] and geodesic active contours [3].

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In these methods, gradient information is usually used to stop a curve at boundaries of objects. Although this works in many cases, the method allows boundary leakage when image gradients are weak and fails to identify object interfaces in the presence of noise.

To overcome these problems, we propose two wavelet-based variational approaches for the segmentation of multivalued images.

In the first approach, a wavelet-based multiscale multistructure tensor is used as an extension of the single-scale structure tensor proposed by Di Zenzo [25]. The multiscale structure tensor allows for accumulating multiscale gradient information of local regions. Thus, with this multiresolution approach, weak edges of multivalued images are identified and different regions interfaces are detected in spite of the presence of noise. Having well identified those edges, image regions and their interfaces are modeled by level-set functions. A functional is defined on these level sets whose minimizers define the optimal classification of objects. Thus, the partition that we seek is a minimizer of a functional. A system of PDE is deduced from that functional. By solving this system, each region evolves and interacts with the neighbor regions in order to obtain a partition with regular contours defined in term of the wavelet transform (WT) by the multiscale multistructure tensor.

It is to be noted that this approach falls in the same category as the work on level-set image classification proposed in [18]. However, it differs from this latter in two main points: first, the approach presented here is for multivalued images. Second, it is capable of performing image partitioning even with the presence of noise and weak edges.

In general, segmentation techniques are developed to capture the object boundary by several different approaches; region-based methods as the proposed wavelet-based level-set method, edge-based methods mainly using active contour models, or the combination of the two by using geodesic active region models. In this work, we are also interested in active contour models. Active contours have been widely used to extract the boundaries of an object in image. Initially, the location of the object under examination is estimated, and a snake is set around the object boundaries. Then, the iterative process is initiated to allow the snake to converge to the likely boundaries. One of the major advantages of the snake over edge-detection algorithms is the continuous representation of the contours. The attractive force to draw the snakes to the object boundaries is the image gradients, which are obtained by means of an edge-detection step to approximate the contour. However, in the case of weak gradients or the presence of noise, the snake model tends to collapse or does not work properly. To overcome these problems, we propose a wavelet-based snake approach. As in the first approach, a multiscale wavelet-based edge detector is used to detect edges of both noisy and unnoisy images and then, the snake is directed toward the detected contours.

The choice of which wavelet to use should be based on the precise contour localization capability of that wavelet. We had the choice between the wavelet-based multiscale edge detector that is used in the proposed region-based level-set segmentation and the foveal wavelets that were first introduced in [10]. The wavelet-based multiscale edge detector is a local smoothing operator that is capable of precisely defining the real boundaries of the image. On the other hand, foveal wavelets are capable not only to precisely detect the image edges but also to describe the smoothness and the orientations of those edges. The smoothness and orientations information could be used to advantage in the process of the snake curve deformation toward the contours of different regions. For this reason, we propose to use foveal wavelets.

It is to be noted also that by using foveal wavelets, edges are detected and characterized from a multiscale foveal energy measurement. Thus, isolated singularities are also detected and the real edges of the image are identified in spite of the presence of noise. This will allow us to obtain a more accurate snake contour. Having well represented the edges, the foveal wavelet coefficients serve as weights that direct the snake curve deformation during the segmentation process. Therefore, a PDE-foveal wavelet-based accurate edge detection is obtained.

We should notice that recently, some authors, and for specific applications, have integrated the WT in the snake approach such as in [5]. However, to our knowledge, foveal wavelets have not been used before in active contour models. Finally, the application of our algorithm to color images showed better results than other color active contour models.

The rest of the paper is outlined as follows. In Section 2.1, a brief review of level-set segmentation model is given. In Section 2.2, a review of the