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A global minimization hybrid active contour model with applications to oil spill images

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ABSTRACT

Active contour model is popularly and widely used in the field of image segmentation, which is based on superior theoretical properties and efficient numerical methods. Nevertheless, one of the prominent disadvantages of this kind of model is the existence of local minima in its functional energy. In this paper, we propose a novel global minimization hybrid active contour model. This model effectively integrates the edge information, the local region information and the global region information of the image, which is relatively sufficient to extract the object boundaries. Furthermore, we introduce an efficient and fast numerical approach to globally minimize the proposed model, which is through a dual formulation of the minimization problem and easy to implement. The proposed model is robust enough to the initial condition and does not need to initialize the contour in a distance function and re-initialize it periodically during the evolution process. Specially, we applied the proposed model to segment oil spill images, in which there usually exist the noise, blurry boundaries, and intensity inhomogeneity. Compared with the state-of-the-art models, experiment results demonstrate the performance and effectiveness of the proposed model with applications to synthetical and real images, especially for oil spill images.

1. Introduction

Image segmentation is always a fundamental and important problem in the fields of image processing and computer vision. The aim is to divide the image into regions which belong to distinct objects in the given image. Up to now, there exist a large number of methods to image segmentation based on the statistical method, variational models and partial differential equations [1–3]. Among these methods, the active contour model, originally proposed in [4], is one of the most successful variational models for image segmentation. It mainly drives an evolving contour to move toward the object boundaries. Starting with the presentation and the application of the level set method [5], as a famous example of geometric active contours, the geodesic active contour (GAC) model [6] was proposed for utilizing the edge information of the image to locate the evolving curve around the object boundaries, which can flexibly deal with the topological changes. Even with effective numerical results and strong theoretical properties, the GAC model is sensitive to the initial condition. In other words, the segmentation quality largely depends on the choice of the initial contour, which implies that a bad initial contour may lead to an unsatisfactory result. On the other hand, based on the classical Mumford–Shah model [7], Chan and Vese [8] proposed a

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two-phase model, called the C–V model, which is widely used for image segmentation. The C–V model is based on the global region information of the image. In [9,10], the authors integrated the edge information and the global region information. In order to segment the image with intensity inhomogeneity effectively, the local region information was incorporated into active contour models and it is worth mentioning that the local binary fitting (LBF) model, also called the region-scalable fitting model, was proposed by Li et al. [11,12]. The LBF model exploits the local region information of the image, which presents a meaningful way to deal with the image with intensity inhomogeneity. However, the LBF model is also sensitive to the contour initialization. In particular, if the initial position of the contour is far away from the object boundaries, the LBF model may be prone to getting stuck in local minima. Furthermore, apart from the LBF model, in [13–15], the authors also employed the local region information, which are satisfactory to the image with intensity inhomogeneity. In [16], considering complementary advantages, the local and global region information of the image were incorporated with each other to obtain more desirable results.

Even a general framework for variational active contour models is popular and widespread in the field of image segmentation. Whereas, as pointed out in [17,18], in many variational models, the energy functional is non-convex and therefore it always has local minima, which means a serious difficulty because the local minima of these models usually provide some poor segmentation results. Hence, in order to avoid the problem of trapping into the local minima, how to satisfactorily initialize the contour plays an important role in these models. The main work in [17] presented that a convex relaxation approach was proposed to overcome the problem of the local minima. From a numerical point of view, Bresson et al. [18] established the theorems to determine the existence of a global minimization of the active contour model. Through a dual formulation of the minimization problem, they provided a practical way to solve the active contour propagation problem toward object boundaries, which is easy to implement. More particularly, this method avoids one of the usual drawbacks in traditional level set methods that consists of initializing the active contour in a distance function and re-initializing it periodically during the evolution process, in which the computational cost is expensive. As previously noted, the conventional approach of solving the C–V model is based on the gradient descent method, which is prone to getting stuck in such local minima. In [19], based on the modified fitting term of the C–V model, the authors proposed a new energy functional that has a stationary global minimum. By introducing the Split Bregman method [20] to image segmentation problems, Goldstein et al. [21] built the convex segmentation schemes to deal with the GAC model and the C–V model, which substantially outperform traditional level set methods. In a recent work, Brown, Chan and Bresson [22] further proposed a completely convex formulation of the C–V model. On the other hand, Jing et al. [23] proposed a new global minimization active contour model (GMACM) to avoid the existence of local minima, which is based on the LBF model. Consequently, this model only employs the local means of image intensities. By designing a statistical energy function for the distribution of each local region in the transformed domain, Song et al. [24] recently proposed a globally statistical active contour model (GSACM), which is convex with respect to the level set function and robust to the initialization. Compared with the GMACM, the GSACM takes into account the local averages and variances of image intensities. In view of the intensity inhomogeneity, noise and weak boundaries of oil spill images, both the GMACM and the GSACM can be used to segment them efficiently.

In this paper, we propose a new global minimization hybrid active contour model (GMHACM), which integrates the edge information, the local region information and the global region information of the image. From the perspective of the energy functional form, the proposed GMHACM is developed from the approach of our previous work [25], which is based on the local and global Gaussian distribution fitting energies. Specifically, inspired by the related contributions in [17,18], a convex relaxation method is designed to solve the model in [25], which contains the weighted total variation (TV) norm and the region information term of the image. In this weighted TV norm, the edge information of the image is incorporated. The GMHACM avoids the existence of local minima and is independent of the initial condition.

Oil spills usually occur in conditions other than illegal discharges from ships result in adverse effects on the natural resources, marine environment and the economic health of the area is at stake. In fact, the images of oil spills taken in broad daylight appear as a blend of dark areas with scintillations of glitter because of the illumination and reflectance components present. Generally, a large number of the dark areas are the regions indicating oil spills because the oil dampens the capillary waves on the sea surface [26]. Actually, the segmentation is a critical method for the location and acreage calculation of oil spill regions in the sea. The presence of the glitter and the dark areas makes automatic segmentation of oil spill images difficult, even though a variety of methods can be applied [27]. Considering the characteristics of oil spill images, such as the blurry boundaries, the various shapes and the existence of intensity inhomogeneity, the GMHACM integrates the edge information, the local and global region information of oil spill images all together, which is relatively sufficient for obtaining satisfactory segmentation results in practical applications.

The outline of this paper is organized as follows. In Section 2, we present the proposed GMHACM in detail. We give some numerical experiments to demonstrate the effectiveness and performance of our model in Section 3. Finally, we summarize this paper in Section 4.

2. The description of the GMHACM

2.1. The previous work

In our previous work [25], we proposed an active contour model for incorporating the local and global region information of the image simultaneously, which was partly motivated by the works [12,14]. First of all, I is supposed as the input image