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An adaptive weighting parameter estimation between local and global intensity fitting energy for image segmentation

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ABSTRACT

Local and global intensity fitting energy are widely used for image segmentation. In order to improve the segmentation quality in the presence of intensity inhomogeneity, in this paper, we propose a new adaptive rule for obtaining weighting parameter estimation between the local and global intensity fitting energy. Following the minimization of the energy functional, the value of the weighting parameter is dynamically updated with the contour evolution, which is effective and accurate for extracting the object.

1. Introduction

Image segmentation is always one of major tasks in image analysis and understanding. Active contour models, as presented in [1–4], based on the theory of curve and surface evolution, and geometric flows have been extensively studied and successfully applied to the field of image segmentation. The original active contour model, also called snake model, was introduced in [2] by employing the explicit curve to extract objects. And because of that, this model always keeps intrinsic disadvantages, such as its difficulty in handling topological changes. In order to solve this problem, level set method [5] which was firstly proposed by Osher and Sethian could handle topological changes effectively by representing curves or surfaces as the zero level set of a high dimensional function. Since the introduction of the level set, it has become increasingly popular as a general framework for image segmentation [6].

Generally speaking, active contour models can be categorized into edge-based models [2,4,7–9] and region-based models [1,10–14]. Edge-based models use edge or gradient information to drive the active contour toward the object boundaries, which are satisfactorily used to segment the image with distinct edges. Nevertheless, these models are sensitive to initial conditions and sometimes with severe boundary leakage problems, especially to the weak or fuzzy boundaries. Region-based models have advantages that they do not rely on any gradient information and are less sensitive to the noise and clutter. Moreover, the results of region-based models are considered less dependent on the initialization as they exploit the region information of image statistics.

Among the region-based models, Chan–Vese (C–V) model [1], as a variant of Mumford–Shah energy functional [15], is defined by minimizing an energy functional to approximate the image in a piecewise constant way. However, the C–V model

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always assumes that the image is statistically intensity homogeneous in every region, which greatly limits its practical applications. Actually, intensity inhomogeneity is a widespread phenomenon, which widely exists in the real world such as medical imaging due to some technical limitations and artificial factors. Up to now, even though a large number of methods for image segmentation have been proposed, intensity inhomogeneity remains a challenging problem as well. Based on the traditional C–V model, a multiphase level set framework [10] is proposed for multi-region image segmentation, which can be used to deal with the problem of intensity inhomogeneity. However, it needs periodical reinitialization of the level set function so as to increase the computational cost, and especially for the image with severe intensity inhomogeneity, the performance may be not satisfactory. In [12,13], local region information has been incorporated into the active contour models, which is called local binary fitting (LBF) model, and performs better than the C–V model on extracting objects for the image with intensity inhomogeneity. But the LBF model is sensitive to the initialization of the contour, and especially if the initial position of the contour is far away from the object boundaries, the LBF model is prone to getting stuck in local minima.

So naturally, how to take full advantages of local and global region information is a significant problem in practical applications. In [16,17], on the basis of employing their complementary advantages, the local and global region information are incorporated with each other to achieve more effective results. These methods directly integrate the local and global region information, which is lack of flexibility. Specifically, in [17], the C–V model and LBF model are combined each other by using a weighting parameter, which is called LGIF model. However, a critical issue for the effective application to the image with intensity inhomogeneity is the correct selection of this weighting parameter. A good selection is benefit to extract the object and reduce the computational cost. Even so, in practical applications, finding a good selection is always time-consuming. On the other hand, the LBF model requires a suitable initialization. Sometimes, selecting a big or small weighting parameter is not desirable when the initial contour is far away from the object boundary in the presence of intensity homogeneity. To be specific, selecting a big weighting parameter may lead to a bad result, and a small one needs high computational cost.

The main contribution of this paper is the proposal of a new adaptive rule for estimating the weighting parameter of the LGIF model [17]. This rule can dynamically update the value of the weighting parameter following the minimization of the energy functional. According to the expression in [17], selecting a big weighting parameter makes the global region information play a dominant role in the energy functional, which is beneficial to reduce the computational cost and sensitivity to the contour initialization. Similarly, selecting a small weighting parameter means that the local region information is leading, which is expected for the image with intensity inhomogeneity. Therefore, we consider to select a relatively big weighting parameter in the beginning, and dynamically update it with the change of the energy functional. By this adaptive estimation of the weighting parameter, it is flexible to initialize the contour. Furthermore, it effectively eliminates the troublesome selection of the weighting parameter.

This paper is organized as follows. In Section 2, we mainly review the popular C–V model, the LBF model and the LGIF model. In Section 3, we propose an adaptive rule for the estimation of the weighting parameter between the local and global region information. In Section 4, we carry out some experiments to demonstrate the effectiveness of the proposed method. Finally, we summarize this paper in Section 5.

2. Background

2.1. C–V model

By simplifying the Mumford–Shah functional [15], Chan and Vese [1] introduced the contour C to divide the image into two regions, which are expressed as $in(C)$ and $out(C)$, and use two constants c_1 and c_2 to approximate the image intensities of every region. The energy functional of the C–V model is defined as follows:

$$E(C, c_1, c_2) = \mu \cdot Length(C) + v \cdot Area(inside(C)) + \lambda_1 \int_{in(C)} |I(\mathbf{x}) - c_1|^2 \, d\mathbf{x} + \lambda_2 \int_{out(C)} |I(\mathbf{x}) - c_2|^2 \, d\mathbf{x}, \tag{1}$$

where $\mu \geqslant 0, v \geqslant 0, \lambda_1 > 0, \lambda_2 > 0$ are parameters, and $\mathbf{x}$ represents a point of the image. The first term of the energy functional (1) is length restraint term of the contour and the second term is area restraint term of inside region. The last two terms are called fitting energy based on inside and outside the contour, which play a major role during the process of the contour evolution.

The C–V model is less sensitive to the contour initialization and with a fast convergence rate. Based on techniques of the curve evolution and the level set method, the C–V model is considered as one of the most widely used models for two region image segmentation. However, as a limitation, the C–V model always assumes the image with intensity homogeneity, which is very idealistic. Besides, it is mainly related to the global properties for they rely on the region information inside and outside the contour, respectively. Due to not taking local image information into account, the C–V model can not effectively deal with the problem of intensity inhomogeneity.

2.2. LBF model

The LBF model [12,13] was primarily proposed for employing local region information to deal with the problem of intensity inhomogeneity in image segmentation. Its energy functional is defined as follows: