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Saliency Snake: A unified framework with adaptive initial curve

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ABSTRACT

Active contour model also known as Snake, is a popular approach for contour extraction and image segmentation. However, some existing active contour models are sensitive to the initial curve, which is usually required to be placed near the true object contour. To address this problem, this paper proposes a novel active contour model with adaptive initial curve, namely Saliency Snake. Taking visual saliency into consideration, prior shape information of the interested object is incorporated explicitly into the energy functional of Saliency Snake. Such improvement facilitates active contour evolution and leads to fast and automatic segmentation. Experiment results demonstrate that the proposed Saliency Snake can achieve superior segmentation performance both in terms of accuracy and efficiency.

1. Introduction

Active contour model using techniques of curve evolution, also known as Snake [1], is an effective and popular approach, and has been widely investigated and applied in the research fields of image segmentation and contour detection in recent years. Originally, active contour models can be divided into two categories: edge-based model [2,3] and region-based model [4,5]. Along with the in-depth study, a new class of active contour model which utilizes both edge-based and region-based information is discussed to segment the image accurately [6,7]. In short, different models have different advantages and disadvantages. But in general, the basic idea in active contour model is to deform an initial curve C evolving toward the true object boundary under some constraints in order to segment the object from the given image I. Hence, active contour model can be easily formulated under a principled energy minimization framework, and allow incorporation of various prior image knowledge, such as shape and intensity distribution. Most of the existing active contour models iteratively evolve the initial curve C around the object specified beforehand by the user, by minimizing an energy functional E. Typically, the energy E is given by summation of two terms: internal energy E_{int} that measures the smoothness of C, and external energy E_{ext} that takes into account how close C is to the true object contour. Therefore, active contour models always produce smooth and closed contours as segmentation results which are useful for further applications. Over the past decades, researches about active contour model have been a hot topic and various approaches have been proposed up to now.

The latest literature about active contour models have mainly focused on increasing the capture range [8,9], improving energy terms [10,11] and extending the application area [12–14]. These research results have improved the performance of active contour model from different aspects and in various domains. By contrast, only a few studies have been reported about initial curve selection or initialization, which is also an important issue for active contour model. The performance of active contour model is affected by initial curve setting, if the initial curve starts in almost the right place, not only the final results can be obtained, but also the time needed for segmentation is reduced drastically [15]. For instance, prior knowledge about objects generated by different saliency detection methods was integrated with a localizing region-based active contour model for traffic sign detection [16] and natural object segmentation [17]. Li and Acton [18] proposed a novel automatic initialization approach by the poisson inverse gradient method in both 2D and 3D images. But their method is limited to parametric active model and discrete active surfaces. Another solution for initial curve setting is to specify by the user, which requires extra manual interventions and is not feasible in practical and real-time applications. Besides the above-mentioned problem, experiment images for active contour model sometimes are simple synthetic images, medical images or a specific type of image.

To address the problems mentioned above, this paper proposes a unified active contour model, namely Saliency Snake, which has an adaptive initial curve derived from visual saliency detection. The proposed Saliency Snake follows the same underlying theory of

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traditional active contour models, but benefitting from the flexible and adaptive initialization, the saliency driven active contour model can accommodate fewer evolution and accurately converge to the object boundary. And experiment results also demonstrate that it allows faster and more accurate convergence by adapting to the image saliency characteristics.

This paper is organized as follows. In the next section, we describe our method in detail and elaborate the numerical implementation. And in Section 3, we validate the proposed method by several experiments on synthetical and natural images, and illustrate the comparison results with some typical active contour models. Meanwhile, experiment analysis are given too in this section. In Section 4, we end the paper by a brief conclusion and give a prospect of the further research based on our work.

2. Proposed saliency snake

Overall, the proposed Saliency Snake automates the initialization of initial curve, using bottom-up visual attention mechanism and morphological operations. It employs a threshold method with spatial and shape restrictions to determine the approximate contour of interest object in a given image. Then, energy functional is constructed according to the initial curve and prior shape information of the interested object is incorporated explicitly. The overall process of the proposed Saliency Snake is described in detail in the following subsection.

2.1. Initial curve extraction

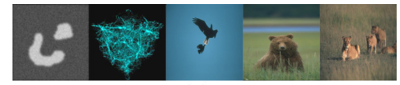
Earlier studies have shown that human vision system has the selective visual attention ability to rapidly detect interesting parts from a given scene, so that to reduce the amount of incoming visual data to a small but relevant amount of information [19]. The selected locations are supposed to represent the most conspicuous parts of the image, known as conspicuous map or saliency map. At present, there are many methods for generating saliency map such as biologically inspired method [20], contrast-based algorithm [21], frequency analysis approach [22], etc. In general, these methods use one or more features to determine local or global contrast of image regions relative to their surroundings. And saliency map has been already utilized for some image segmentation problems [23,24]. Inspired by these earlier research about active contour model and visual saliency detection, we attempt to construct a unified active contour model with adaptive initial curve C derived from saliency map for automatic and fast image segmentation.

It was pointed out and proved that the phase spectrum of image Fourier Transform is the key to extract the location of interested parts [25]. So in order to provide the initial curve automatically and adaptively, similar idea is adopted here as the saliency detection scheme due to its low computational cost, full resolution and unsupervised manner. For a given image $I(x, y)$, its saliency map $SM(x, y)$ is calculated as follows:

$$\begin{cases} f(x,y) = F(I(x,y)) \\ p(x,y) = P(f(x,y)) \\ SM(x,y) = g * \|F^{-1}[e^{i\cdot p(x,y)}]\|^2 \end{cases} \tag{1}$$

where F and F^{-1} refer to the Fourier Transform and Inverse Fourier Transform, respectively. $p(x, y)$ means the phase spectrum of the image, and g is a 2D Gaussian filter ($\sigma = 8$) for a better visual effect.

Saliency map generated by Eq. (1) is a gray level image, which represents the salient value of each pixel. The salient values range from 0 to 255, and the larger the salient value, the more likely the pixel attract observers' interest. Next, the overall binary curve map BCM can be obtained by a binarization of $SM(x, y)$:



(a)

(b)

Fig. 1. Some examples of initial curve extraction results. (a) Input images; (b) initial curves.

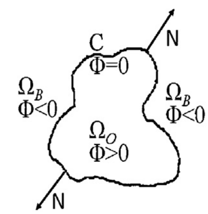


Fig. 2. Initial curve C and value of ϕ.

$$BCM(x,y) = \begin{cases} 0 & \text{if} \quad SM(x,y) < t \\ 1 & \text{if} \quad SM(x,y) \geq t \end{cases} \tag{2}$$

The binarization threshold t is set to be the value which maximizes the discrimination criterion $\left(\sigma_B^2/\sigma_W^2\right)$ of two classes (object and background), where σ_B^2 is the between-class variance and σ_W^2 is the within-class variance, respectively.

Finally, morphological closing operator is used on BCM to fill the holes in the salient object, and initial curve can be extracted as shown in Fig. 1. These test images have different content and features. It can be seen that these closed and irregular initial curves derived from saliency map are diverse according to different image content, and each initial curve is near and contains most of the salient object. Furthermore, the initial curves are provided automatically and adaptively compared with traditional methods, and they can be used for active contour models.

2.2. Energy functional and level set implementation

Next, instead of manually positioning a rectangle or a circle as initial curve, Saliency Snake with adaptive initial curve based on visual saliency detection is proposed. Input image $I(x, y)$ is divided into two regions by initial curve C, namely object region Ω_O and background Ω_B, which can be seen as prior shape approximation of salient object and background, respectively. And the values c_o and c_b are mean intensities of two regions Ω_O and Ω_B, respectively. Then a prior saliency shape fitting energy functional is defined as:

$$E^{SS}(C, c_o, c_b) = \lambda_1 \int_{\Omega_O} |I - c_o|^2 dxdy + \lambda_2 \int_{\Omega_B} |I - c_b|^2 dxdy \tag{3}$$

where λ_1, λ_2 are fixed parameters. In our numerical calculations, we set $\lambda_1 = \lambda_2$.

Generally, the minimization problem of energy functional E will be converted into solving partial differential equations by using level set method [26]. So firstly, an appropriate level set function $\phi(x, y)$ is chosen which satisfies the condition $\phi_0(x, y)$, that is, the zero level set function is corresponding to the initial curve C. Choice of level set function is not unique, as generally setting, here $\phi(x, y)$ is set as a signed distance from a pixel (x, y) to initial curve C, namely signed distance function (SDF), as shown in Fig. 2. So according to