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Review

Multiscale geodesic active contours for ultrasound image segmentation using speckle reducing anisotropic diffusion

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ABSTRACT

Image segmentation is a fundamental but undoubtedly challenging problem in many applications due to various imaging artifacts, e.g., noise, intensity inhomogeneity and low signal-to-noise ratio. This paper presents a multiscale framework for ultrasound image segmentation based on speckle reducing anisotropic diffusion (SRAD) and geodesic active contours (GAC). SRAD is an edge-sensitive diffusion tailored for speckled images, and it is adopted here to reduce speckle noise by constructing a multiscale representation for each image where the noise is gradually removed as the scale increases. Then multiscale geodesic active contours are applied along the scales in a coarse-to-fine manner to capture the object boundaries progressively. To avoid boundary leakages in low contrast images, traditional GAC model is modified by incorporating the boundary shape similarity between different scales as an additional constraint to guide the contour evolution. We compare the proposed model with two well-known segmentation methods to demonstrate its superiority. Experimental results in both synthetic and clinical ultrasound images validate the high accuracy and robustness of our approach, indicating its potential for practical applications in other imaging modalities.

Contents

1. Introduction

Ultrasound imaging has been widely used in many diagnostic and therapeutic applications because of its diverse advantages, such as accessibility, safety and portability. Correct localization [1] or contour extraction [2] of interested objects plays an important role for disease diagnosis and treatment planning. However, accurate ultrasound image segmentation is still a challenging problem [3] due to various ultrasound artifacts, including high speckle noise [4], low signal-to-noise ratio and intensity inhomogeneity [5]. In clinical practice, the segmentation task is generally performed by manual tracing, which is tedious, time-consuming,

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and skill- and experience-dependent. Moreover, the ultrasound specialists can suffer from Repetitive Stress Injury (RSI) due to the tedious and repetitive keystrokes. Hence, to improve the diagnosis and treatment performance, reliable and automatic or semiautomatic segmentation methods are required to precisely detect different types of tissues and structures from ultrasound images.

A lot of approaches have been proposed in the literature for ultrasound image segmentation. Early investigations try to analyze the statistics of speckle noise [6] and utilize some filtering techniques to enhance the image quality before segmentation [7–9]. Statistical models are extensively studied and several probability density functions have been employed to model the intensity distribution of ultrasound data [10–12]. Other work dedicating to segmenting ultrasound images includes deformable models [13], multiscale techniques [14,15] and fuzzy logic [16]. Besides, shape knowledge is also of great interest in many applications [17,18]. However, inclusion of *a priori* shape information may lead to erroneous segmentation results if the targets are deformed due to pathological changes.

Active contour models (ACMs) [13], based on the deformation of a contour to reach object boundaries according to internal and external energy, are widely investigated for image segmentation. Depending on the type of driving force, existing active contour models and their level set formulation [19] can be broadly categorized into two classes: edge-based models [20–22] and region-based models [23–25]. In the field of echography, Mikic et al. [26] designed an active contour framework to segment and track echocardiographic sequences, where initial contour of the present frame is estimated from the result of previous frame using optical flow. In [27], Liu et al. used the probability density difference of image intensity to segment breast ultrasound images. Using maximum likelihood approach, Sarti et al. [11] modeled the gray level of ultrasound images with Rayleigh distribution and Rahmati et al. [51] employed the two-parameter Gamma distribution to improve the accuracy of mammography segmentation. Moreover, local phase information is also exploited for feature detection in echocardiographic data [28–30], arguing that phase-based methods are more suitable for ultrasound image segmentation since they are invariant to variations in image contrast. However, most of these methods do not fully consider the impact of speckle noise, and require careful tuning of the parameters to avoid trapping into local solutions.

Multiscale approach has been demonstrated to be an efficient technique to reduce the computational cost and the risk of converging to local minima [31]. Bresson et al. [32] proposed a multiscale segmentation framework based on the active contour model. This technique is also adopted in [14,15] for ultrasound image segmentation. It relies on the conversion of speckled images with Rayleigh statistics to subsampled images with Gaussian statistics by building a Gaussian pyramid [33]. High-frequency noise is smoothed out at coarse scales of the pyramid and neighboring pixels in these scales are more likely to be independent as subsampling reduces their correlation. According to Central Limit Theorem, the intensity distribution of these pixels can be approximated as Gaussian statistics, which is far more mathematically tractable and separable than Rayleigh statistics that actually characterizes ultrasound images. However, as quoted in [34], the major drawback of traditional low-pass filtering and linear diffusion for noise reduction is the blurring of edges, thus it is difficult to accurately detect and locate the semantically meaningful edges at coarse scales. In contrast, nonlinear diffusion [35,36] has been shown to perform well for noise filtering and edge detection. Shah [37] integrated different versions of curve evolution into a new segmentation functional, which can be used as a basis for deriving new approximate methods for acceleration, e.g., anisotropic diffusion. Meanwhile, Sapiro [38] showed the relations between classical active contours and anisotropic diffusion flows. In [39], Alemán-Flores et al. combined an anisotropic filter and geodesic active contours in a multiscale framework for breast tumor segmentation. However, their method does not exploit the geometric information between different scales and also suffers the weakness that comes with Gaussion smoothing.

In this paper, we present a multiscale segmentation framework for ultrasound regions based on speckle reducing anisotropic diffusion (SRAD) and geodesic active contours (GAC). SRAD is a diffusion method that encourages intra-region smoothing in preference to inter-region smoothing. We first employ SRAD to construct a multiscale representation for each input image. General information is extracted at coarse scales and details about local structures are maintained at fine scales. Furthermore, speckle noise is gradually reduced as the scale increases while the object boundaries are still preserved, or even enhanced. Then multiscale geodesic active contours are applied along the scales from coarse

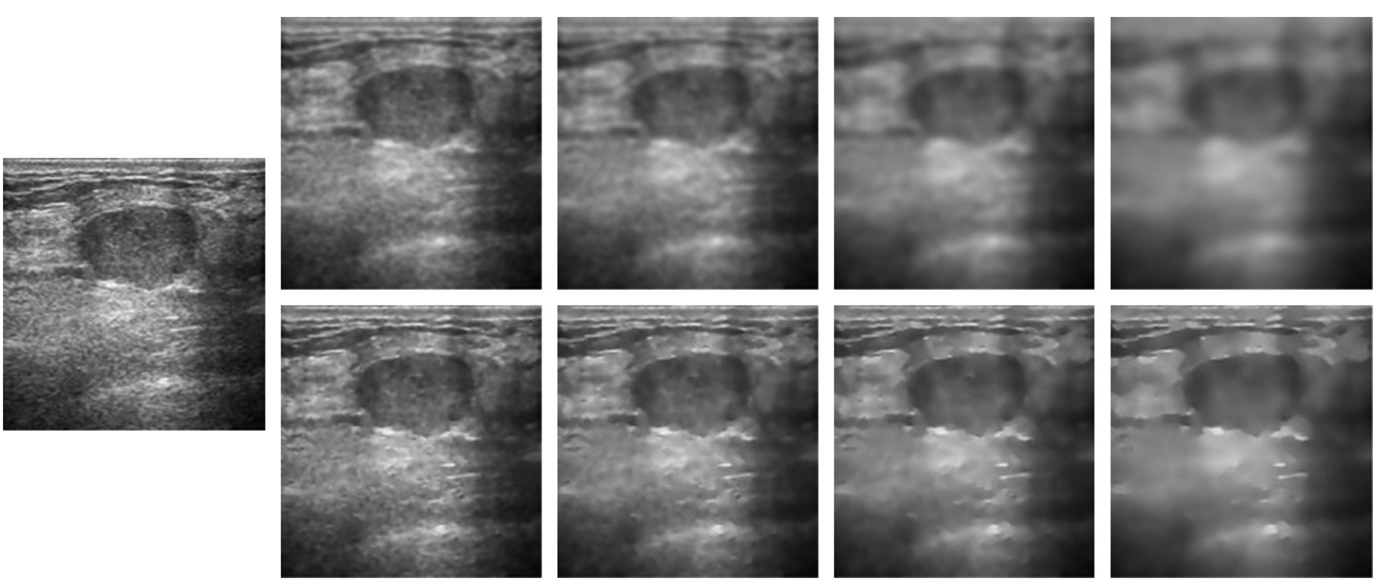

Fig. 1. Comparisons of speckle reduction by different filtering schemes. (Left) An ultrasound image of breast tumor. (Top row) Speckle reduction by Gaussian filtering. From left to right, the noise in the image is gradually smoothed out as the variance of Gaussian kernel increases, but the edges of breast tumor are also blurred. (Bottom row) Speckle reduction by SRAD filtering. As the scale increases, SRAD both reduces speckle noise and preserves the tumor boundaries.