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Accurate vessel segmentation in ultrasound images using a local-phase-based snake

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ABSTRACT

Accurate vessel segmentation in ultrasound images is difficult to realize given the poor image quality of such images. In this study, a local-phase-based snake is proposed to improve the accuracy of vessel segmentation in ultrasound images. In the proposed snake framework, image energy is generated using the local phase of the ultrasound image. By using the intensity-invariant local phase, we can obtain identical image energies on all edges regardless of the strengths of their intensity contrasts. In addition, by minimizing the identical local-phase-based image energy, the snake can be pulled uniformly toward the strong and weak edges, and accurate vessel segmentation in ultrasound images can be achieved. The performance of the proposed segmentation method is evaluated using three types of vessels. We then compare it with the performances of the gradient-based standard snake and snake that uses the balloon model. The evaluation results show that the proposed local-phase-based snake accurately segments vessels from ultrasound images and performs better than the known methods.

1. Introduction

Vascular ultrasound is a non-invasive, inexpensive, and real-time method used in diagnostics related to arteries and veins and in surgical navigation systems. Because arteries and veins are distributed in nearly every part of the human body, the vascular ultrasound targets a wide range of blood vessels, such as those in the neck, abdomen, arms, and legs. Thus, there are many applications of vascular ultrasound, some of which are described in recent studies [1–5]. In these vascular ultrasound applications, vessel segmentation is a critical process. However, the image quality of ultrasound images is generally poor because of low signal-to-noise ratio, speckle noise, low contrast, or local intensity changes. Poor image quality makes detection of true vessel edges difficult, thereby affecting the accuracy of vessel segmentation in ultrasound images.

Several approaches have been proposed to segment vessels in ultrasound images. Mao et al. have proposed a method to segment the carotid artery in ultrasound images using a deformable model driven by both internal and gradient-based external forces [6]. To reduce the effect of noise in ultrasound images on vessel segmentation, Hamou et al. have proposed a new snake framework in which the snake contour is converged to the one-response result of a modified Canny edge detector [7]. Stoitsis et al. have used the Hough transform to initialize gradient-based active contours to achieve automated artery segmentation in ultrasound images [8]. Zhu et al. have proposed a segmentation method that uses a gradient-vector-flow-based snake to segment the vessel wall in intravascular ultrasound images [9]. Jorgensen et al. have used a multiscale snake to perform vessel segmentation in ultrasound images [10]. Chen et al. have proposed an automated method to segment the common carotid artery in ultrasound images. The method uses an active shape model with a knowledge-based seed-point detection method [11]. Qian et al. have combined a gradient-based snake and speckle-tracking model to segment the internal jugular vein in ultrasound images [2]. Smistad et al. have proposed an ellipse fitting method to segment the femoral artery in ultrasound images, and have used normalization of the image gradient in artery detection [4].

In general, segmentation accuracy is mostly determined by the feature used to guide the global optimization process, regardless of the type of framework selected for segmentation [12]. In previous studies concerning vessel segmentation in ultrasound images [2,4,6–11], the intensity and gradient features were frequently used

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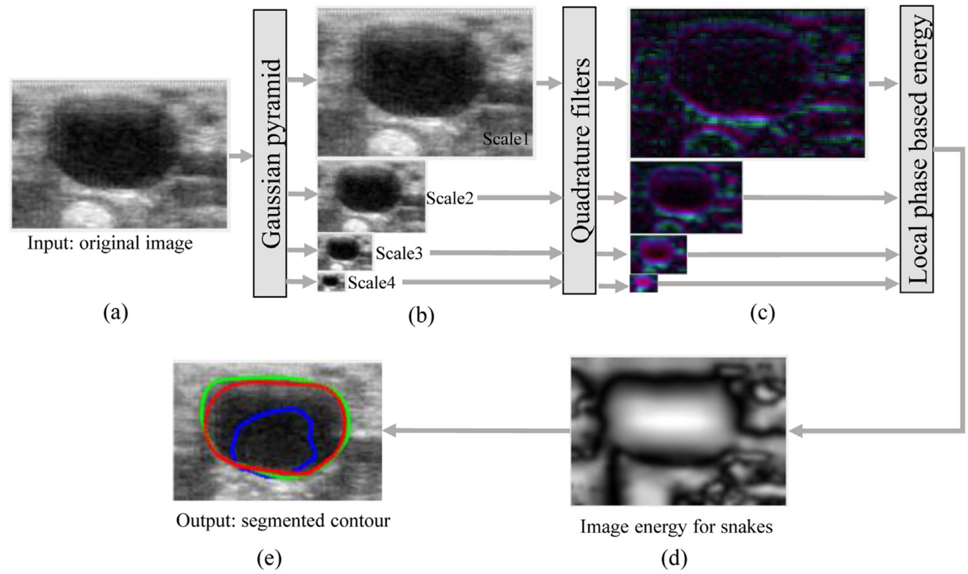

Fig. 1. Dataflow of the proposed local-phase-based snake framework for vessel segmentation in ultrasound images.

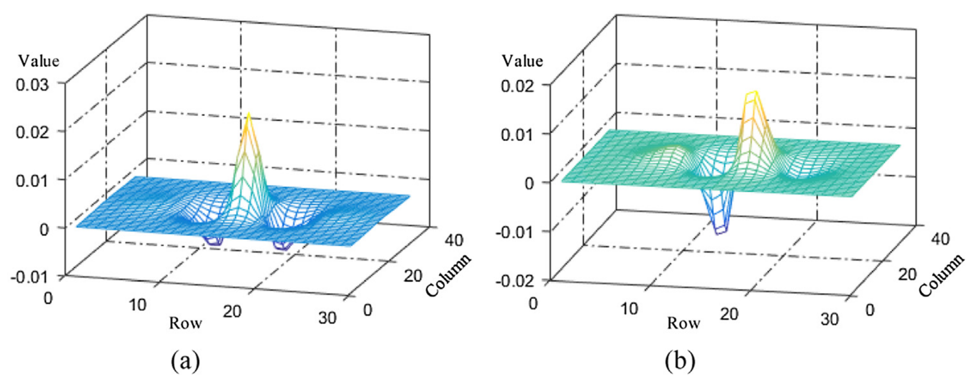

Fig. 2. Example of a quadrature filter in spatial domain: (a) real filter, (b) imaginary filter.

to detect vessel areas or edges. However, these features are directly influenced by the poor image quality of ultrasound images, making it difficult to achieve accurate and robust results.

In recent years, local phase, which is an intensity-invariant image feature, has attracted considerable attention [13–20], particularly in segmentation-related applications. Ali et al. have used local-phase feature to segment transparent cells in microscopic images, which have features of low contrast and weak intensity variation [15]. Hacihaliloglu et al. have used local-phase feature to segment a bone and detect fractures in ultrasound images [16,17]. Lathen et al. have applied a local-phase-based level set method to segment blood vessels in two-dimensional (2D) retinal images [18]. Rajpoot et al. have used local-phase feature to detect the boundaries of the left ventricle in ultrasound images [19]. Belaid et al. have introduced local phase to the framework of the level-set method to segment the left ventricle [20]. In local-phase-based segmentation applications, the level-set method is the primary segmentation framework. However, level-set segmentation methods cannot effectively address contours with leakages [20,21], such as specific vessel contours in ultrasound images. Therefore, the local-phase-based level-set method is not suitable for segmenting vessels in ultrasound images.

In this study, a local-phase-based snake is proposed to achieve accurate vessel segmentation in ultrasound images. The local phase of ultrasound images is first estimated using quadrature filters in multiple image scales, which are generated using Gaussian pyramid. The image energy of the snake is then calculated based on the estimated local phase. As the local phase is intensity-invariant, identical image energies on all edges can be obtained regardless of their strengths. By using identical image energies, the snake points can be pulled toward all edges equally, resulting in accurate segmentation. Compared to the previous methods in which intensity and gradient features are used, the local-phase-based snake can segment vessels in ultrasound images more accurately.

The remainder of this paper is organized as follows. Section 2 presents the proposed local-phase-based snake. Section 3 describes an experimental evaluation method and presents the evaluation results. Section 4 provides a comparison between the proposed method and the known methods. Section 5 presents our conclusion.

2. Method

The dataflow of the proposed local-phase-based snake is shown in Fig. 1. First, the original ultrasound image (Fig. 1(a)) is decomposed into several image scales (Fig. 1(b)) using a Gaussian image pyramid. Second, the decomposed image scales are filtered using quadrature filters to estimate the local phase of the original image (Fig. 1(c)). Then, the image energy of the proposed snake framework (Fig. 1(d)) is calculated using the filter responses derived from the quadrature filters. Finally, the image energy is introduced into the standard snake for vessel segmentation. Note that the green, blue, and red lines in Fig. 1(e) represent the ground truth of the vessel