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Liver vessel segmentation based on centerline constraint and intensity model

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ABSTRACT

Liver vessels provide lots of important information for liver-disease diagnosis and liver surgery. This paper presents an effective liver vessel segmentation method from abdominal computer tomography angiography (CTA) images. The proposed method applies two techniques including centerline constraint and intensity model for effective detection of liver vessels, in which the former aims at generating the position and distance restraints for the detection of thin vessels by the offset medialness filter and height ridge traversal algorithm, while the latter is mainly used to extract intensity feature for the detection of thick vessels based on Kernel Fuzzy C-Means (KFCM). And then, the centerline constraint and intensity model are integrated into graph cuts for ultimate liver vessel segmentation. The proposed method does not require any manual selection of the initial vessel regions, and is capable of dealing with complex liver vessel systems. The experimental results on clinical CTA data sets give an average accuracy, sensitivity, and specificity of 97.4%, 83.0%, and 98.1%, respectively, which show the efficiency of the proposed method on liver vessel segmentation.

1. Introduction

Liver vessel segmentation from abdominal computer tomography angiography (CTA) images is an essential and vital step for computer-aided diagnosis, imaging-guided liver radiotherapy treatments, vessel disease quantification, and living-related liver transplants [1,2], and receives much research attention these days. For example, it is crucial to provide the surgeon with a patient-individual 3D liver vessel system for the planning of liver surgery, and helps to locate tumors as well as make the best operation scheme according to the analyses of liver vessel branching pattern and morphology [3]. In addition, the ablation techniques for liver cancer also rely on an accurate vessel detection to select the puncture path [4]. However, automatic segmentation for liver vessels in CTA images is a challenging task due to the affection of highly ramified branches, low contrast between thin vessels and background, pathological deformation, serious noise and intensity inhomogeneity [5,6]. In fact, a precise segmentation of liver-vessel system is usually performed by experienced radiologists on each slice, which is very dull and also highly laborious task since an abdominal volume generally consists of hundreds of slices. Moreover, the segmentation accuracy highly depends on the experience and skills of radiologists.

Several automatic or semi-automatic approaches have been reported to realize 3D vessel/tubular detection and segmentation, and they mainly focused on devising effective vessel filters [7]. Usually, 3D vessels in medical images such as CTA and Magnetic Resonance Imaging (MRI) can be treated as tubular structures, appearing as symmetrical circular or elliptic cross-section. Based on this characteristic, Frangi et al. [8] developed a multi-scale tubular filter according to the ratio of Hessian eigenvalues, and Jerman et al. [9] subsequently optimized this ratio by imposing a relaxed constraint on vessel shape to obtain a close-to-uniform response. To overcome the disturbance caused by closely located objects like intertwined or parallel vessels, Xiao et al. [10] introduced a bi-Gaussian filter by an integration of two Gaussians with different parameters for the detection of adjacent curvilinear structures. Compared with the Hessian based approaches, the bi-Gaussian filter can minimize adjacent disturbances. In [11], Law and Chung developed an optimal oriented flux filter to measure tubular structure, which is implemented by computing an optimal projection direction minimizing the inward oriented flux at the boundary of

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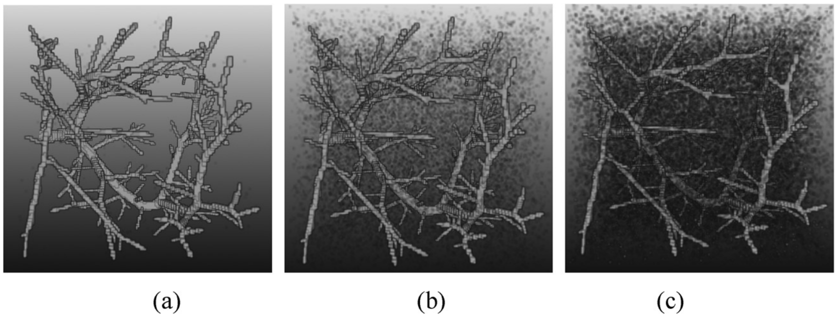

Fig. 1. Example of 3D synthetic vessel image corrupted by different Gaussian noise. (a) Original 3D synthetic vessel image, and (b) and (c) its corresponding Gaussian-noise-corrupted images with σ^2 =20 and 60, respectively.

localized spheres of different radii. This filter was verified to be robust against image noise and interference of closely adjacent structures.

Some other efforts have also been made for 3D vessel segmentation. By inspecting capillary effects with incompressible fluid, Yan et al. [12] introduced a capillary geodesic active contour for the extraction of thin vessels from MRA images. Cheng et al. [13] introduced an active contour framework with shape and size constrains on the cross-section of vessels, which starts with a vessel axis tracking in a 3D CTA data, followed by vessel boundary delineation on the vessel cross-section from this axis, and then applies a snake model to segment vessels under the shape and size constrains. To improve the segmentation efficiency, Smistad et al. [14] proposed a fast method for tubular structure extraction utilizing the computational power of modern Graphic Processing Units (GPU), which can extract 3D vessels in 3–5 s. By regarding the second order intensity statistics as the forces acting on the deforming surface, a physics-based deformable surface model was employed by Law and Chung [15] to extract 3D vessels. This model shows a good performance on reducing the influence of intensity contrast fluctuations along blood vessels. Recently, Wang et al. [16] proposed a thresholding segmentation algorithm to extract cerebral vessels based on the comparison of the probability density functions of two statistical distributions including weighted normal distribution and Gumbel distribution.

Due to the complexity of liver vessels, especially to the weak boundary of thin vessels and intensity difference between thin and thick vessels, simultaneous effective segmentation of these vessels is still a challenging task. In this paper, we present an effective method for liver vessel segmentation based on centerline constraint and intensity model. The former is used to generate position and distance restraints to compensate the weak response of thin vessels, and the latter learn intensity features of thick vessels. They are then integrated into graph cuts for an effective segmentation of liver vessels. Our method is capable of dealing with complex liver vessels, and achieves better segmentation performances than some existing 3D vessel segmentation methods.

2. Materials and methods

We evaluate the algorithm through two data sets including a synthetic data set and a clinical CTA data set. The former is generated by the VascuSynth software [17,18], a tool to simulate volumetric images of vascular trees and to generate the corresponding ground truth segmentations. It contains 3 vessel images with a volume size of 100 × 100 × 100, which are available online at http://vascusynth.cs.sfu.ca/Data.html (2011 VascuSynth Sample). To simulate realistic 3D medical images, we add different Gaussian noise to synthetic images, as shown in Fig. 1, where Fig. 1(a) is an original synthetic vessel image, and Fig. 1(b) and (c) are its corresponding Gaussian-noise-corrupted images with $\sigma^2 = 20$ and 60, respectively.

The clinical data set includes six abdominal CTA volumes at the portal venous phase, two of which are pathologic. Each volume consists of a series of 2D CT slices with 512 × 512 axis plane resolution and each slice of thickness 0.5–2 mm. The number of slices in each volume ranges from 212 to 395. For intuitive display, Fig. 2 shows three typical CT slices acquired from the same abdominal CTA volume, where the closed regions labeled by red curves represent the liver regions.

2.1. Overview of the proposed method

Fig. 3 shows an overview of the proposed method. It begins with preprocessing to generate the liver region and remove noise. Then, according to vessel geometrical structure and shape prior, a centerline constraint method based on the offset medialness filter and height ridge traversal algorithm is proposed for the detection of thin vessels, and an intensity model based on Kernel Fuzzy C-Means (KFCM) is developed to extract the intensity feature of thick vessels. Finally, the centerline constraint and intensity model are effectively integrated into graph cuts cost function to obtain the final liver vessels.

Fig. 2. Typical CT slices acquired from the same abdominal CTA volume.