An Automatic Pulmonary Vessel Segmentation Approach

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1 Introduction

We presented an automatic pulmonary vasculature segmentation approach, one of the modules in our pulmonary artery-vein separation framework. Figure 1 demonstrates the process of the vessel segmentation. Given the input CT scan, we compute the hessian-based vesselness for voxels within the lung. Then Vesselness-Oriented Level Set (VOLES) utilizes the vesselness as growing forces and extracts vessels. In order to remove false positive segmentation, a simple thresholding method and connected component analysis are applied. A binary result is obtained after these steps. Finally we reconstruct a fuzzy segmentation by applying a Gaussian kernel.

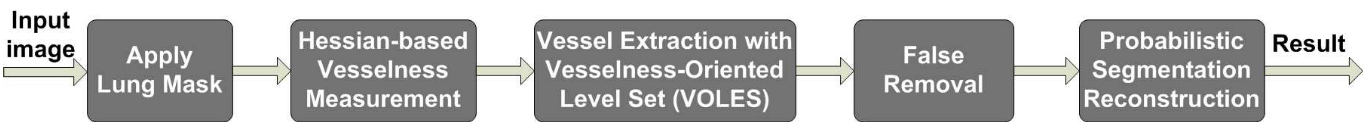

Fig. 1. Modular representation of the pulmonary vasculature segmentation framework.

2 Method

2.1 Vesselness Measurement

We calculate the vesselness $\mathcal{V}$ with Zhou's equation [1] instead of Frangi's. Based on the Hessian matrix H we compute the eigenvalues λ_1, λ_2, and λ_3 with $|\lambda_1| \le |\lambda_2| \le |\lambda_3|$.

$$\mathcal{V} = \begin{cases} \frac{|\lambda_2|+|\lambda_3|}{2} \exp\left(-\left|\frac{|\lambda_3|}{\sqrt{\lambda_1^2+\lambda_2^2+\lambda_3^2}} - c\right|\right) & \text{otherwise} \\ 0 & \text{if } \lambda_1 > 0 \text{ or } \lambda_2 > 0 \text{ or } \lambda_3 > 0 \end{cases}$$

2.2 Vesselness-oriented Level Set (VOLES)

Vesselness-oriented Level Set [2] is employed to extract vessels. VOLES extends the traditional level set formulation for vasculature segmentation,

$$\frac{\partial \psi}{\partial t} + F|\nabla \psi| = 0$$

where $F = g(v_0 - \alpha \cdot e^{(-\beta \cdot \mathcal{V})^3} \cdot k)$, v_0 is an external force, k is the local curvature, and α,β are two constants. As can be seen, the propagation force is weighted by the vesselness $\mathcal{V}$.

The modification of the traditional formulation makes VOLES more suitable to vasculature segmentation, so that the evolving front grows faster along the vessel while maintaining the smoothness of the vessel walls. In order to increase the sensitivity for small vessels, the lower intensity threshold of VOLES is set to -670. Consequently, VOLES labels other non-vessel voxels with high intensity value as in-vessel, such as abnormalities or noises.

2.3 False Removal

In order to remove these false positive voxels, we use a simple thresholding technique and connected component analysis. By thresholding on vesselness, voxels with less than 10% of the maximum vesselness are removed from the segmentation. Then connected component analysis removes small isolated components, generated by noises, from the segmentation. The post-processing stage significantly removes large false positive voxels, and maintains the morphologic structure of the vessels.

2.4 Probabilistic Reconstruction

The probabilistic results Pr are generated by applying a Gaussian kernel (kernel size equals to 6) to the dilated binary vessel segmentation B. For each voxel t that $B(t) = 1$, $Pr(t) = G(t; \sigma)$, where $\sigma = 1.5$.

3 Discussion

Our approach is designed as one step for the pulmonary artery-vein separation in the CAD system of pulmonary embolism detection. Because pulmonary embolism only occurs in pulmonary arteries. The pulmonary embolism voxels are correctly segmented in our own test data. However, our approach has difficulties to exclude other abnormalities with high intensity values from the final segmentation, such as nodules.

Our approach is implemented in MATLAB and C++ on a PC with Intel 2.67 GHz processor and 12GB RAM. The average running time is 25 minutes for 300 iterations of VOLES.

References

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2. Zhu, X. and Xue, Z., Gao, X., Zhu, Y., Wong, S.T.C., VOLES: Vascularity-Oriented LEvel Set algorithm for pulmonary vessel segmentation in image guided intervention therapy, ISBI, 2009.