UNDECIMATED HIERARCHICAL ACTIVE CONTOURS FOR OCT IMAGE SEGMENTATION

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Introduction

A limitation of Optical Coherence Tomography (OCT) image segmentation is the poor signal-to-noise ratio of the imaging process, particularly because images are sampled quickly, at high resolutions, and in-vivo. Furthermore, speckle noise is generated by the reflections of the OCT LASER.

Fig.1 shows the two main challenges for OCT image segmentation, namely the speckle noise and the low signal to noise ratio. Those challenges, in most cases, make the process of automatic OCT image segmentation unreliable and inaccurate and need human interaction.

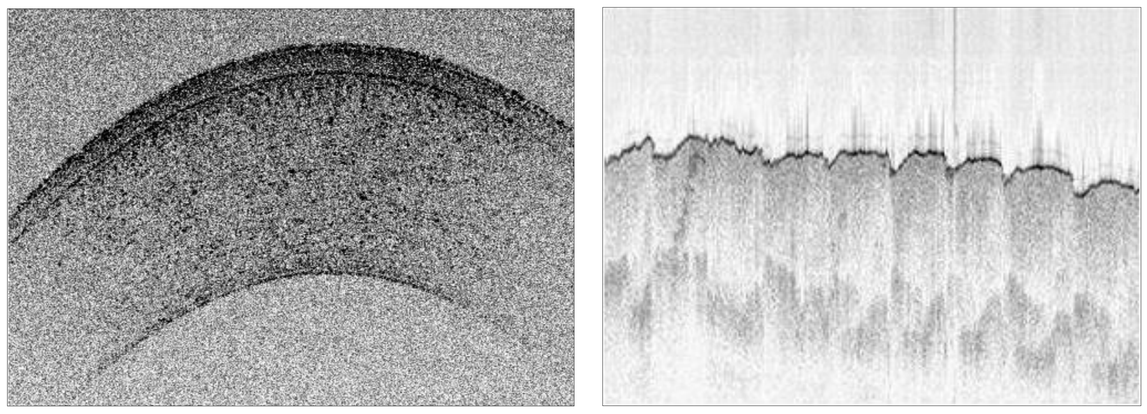

Fig. 1: The significant noise of OCT images forms a great challenge to automatic segmentation methods, as shown here for in-vivo imaging of a human cornea, and of the surface of the skin.

Because OCT is widely used in imaging the cornea, retina, and skin, OCT image segmentation is of key interest in all applications. In this paper, a multi-resolution parametric active contour is used for OCT segmentation.

Using the organ shape as a prior, the image is filtered using a directional smoothing kernel. Furthermore, the undecimated wavelet transform is used to provide us with 1) scale-dependent noise reduction, 2) delocalized salient features (edges) at high scales of the transform due to the absence of down sampling.

The problem of the active contour initialization is addressed using the generalized Hough transform. Experimental results show that the proposed method outperforms classical as well as state-of-the-art methods.

Directional Noise Removal

Based on the prior information of the underlying organ shape, the proposed method directionally filters the image using a spatially varying smoothing kernel *h(x)*

$$\hat{I}(x) = h(x) * I$$

Directional filtering enhances the OCT signal especially at image peripherals where the signal strength is usually weak. The direction of the kernel *h* is determined based on the spatial location of the kernel centre.

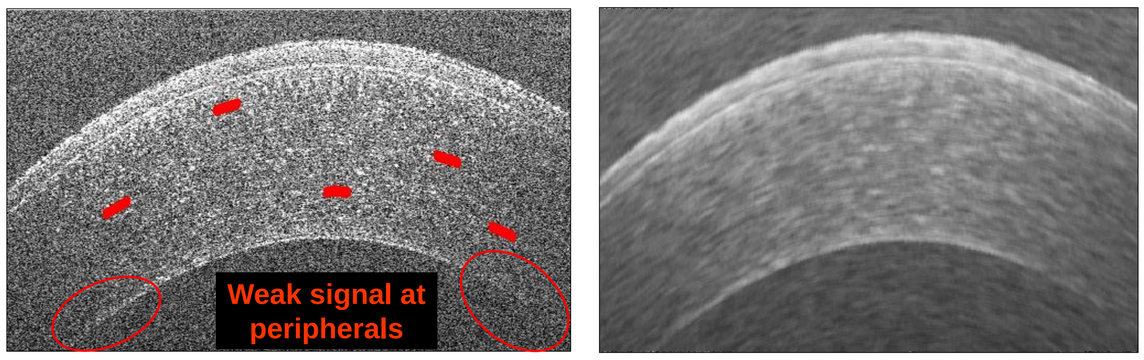

Fig. 2: The weak signal at cornea peripherals causes the active contour to be misguided by the speckle noise. A spatially varying kernel h (red patches) is used to enhance the received signal.

Undecimated Wavelet Transforms (UWT)

The shift invariant property of the UWT, made possible by the absence of down sampling, makes the UWT a perfect choice for multi-scale image denoising and segmentation problems, especially in very noisy environments like the OCT where edge preservation in high scales becomes a challenge.

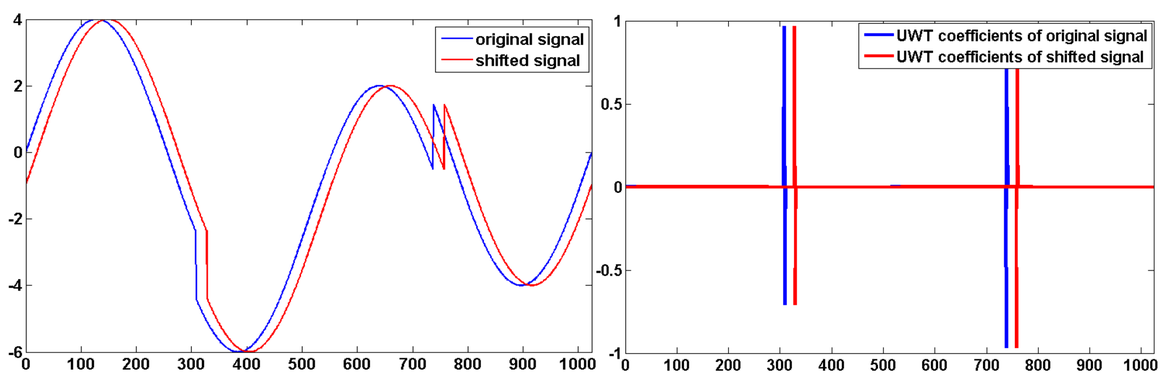

Fig. 3: A small shift in the original signal produces a shift in the transform coefficients c_j . Shift invariant makes the UWT a prefect candidate for image denoising and segmentation.

Hierarchical Active Contours

As is common for active contours, we wish the contour to be attracted to image gradients, so at each resolution of the UWT a gradient map M_J of the UWT approximation image c_j is calculated as

$$M_j = \sqrt[2]{(\partial c_j/\partial x)^2 + (\partial c_j/\partial y)^2}$$

Since salient feature are preserved at coarser scales of the UWT, coarse scale gradients are given preference over fine scale gradient

$$M_T = \sum_{j=1}^{N} 2^j \, M_j$$

Fig. 4 illustrates the improvement of pulling forces (gradient map) as we move from fine to coarse scales of the UWT

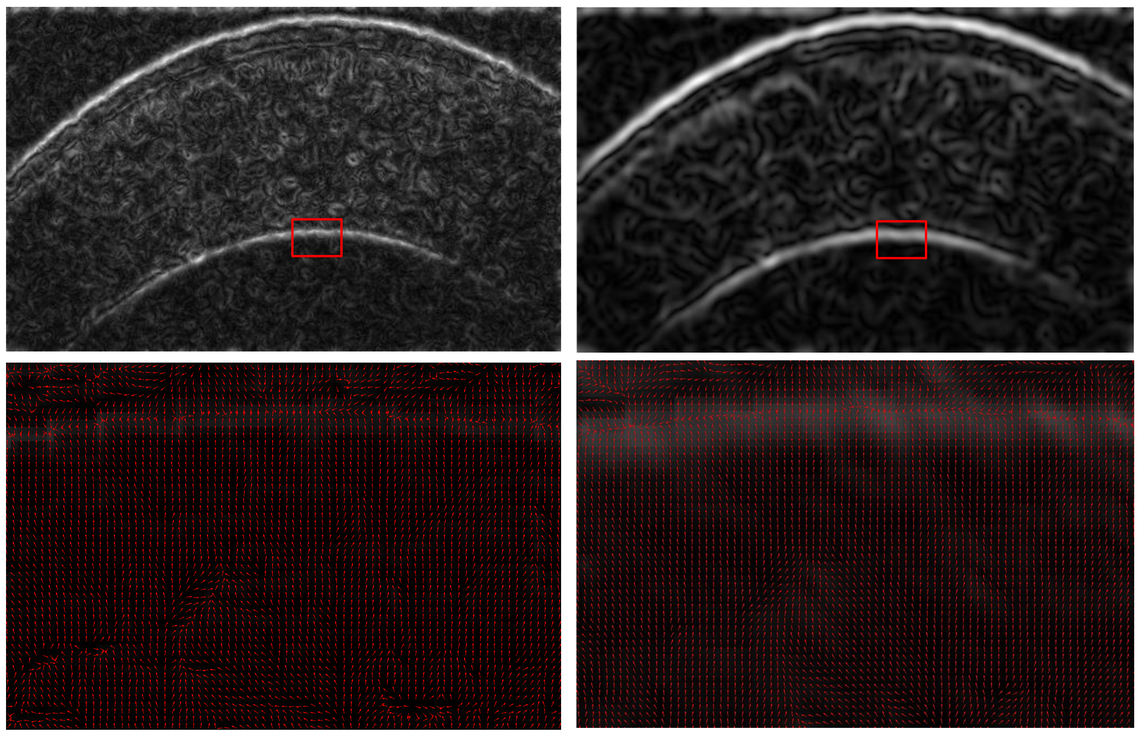

Fig. 4: The weighted gradient map M_T for two (top left) and five (top right) scales of the UWT. The external forces (red arrows) becomes less noisy and more consistent as the number of used scales increases.

Experimental Results

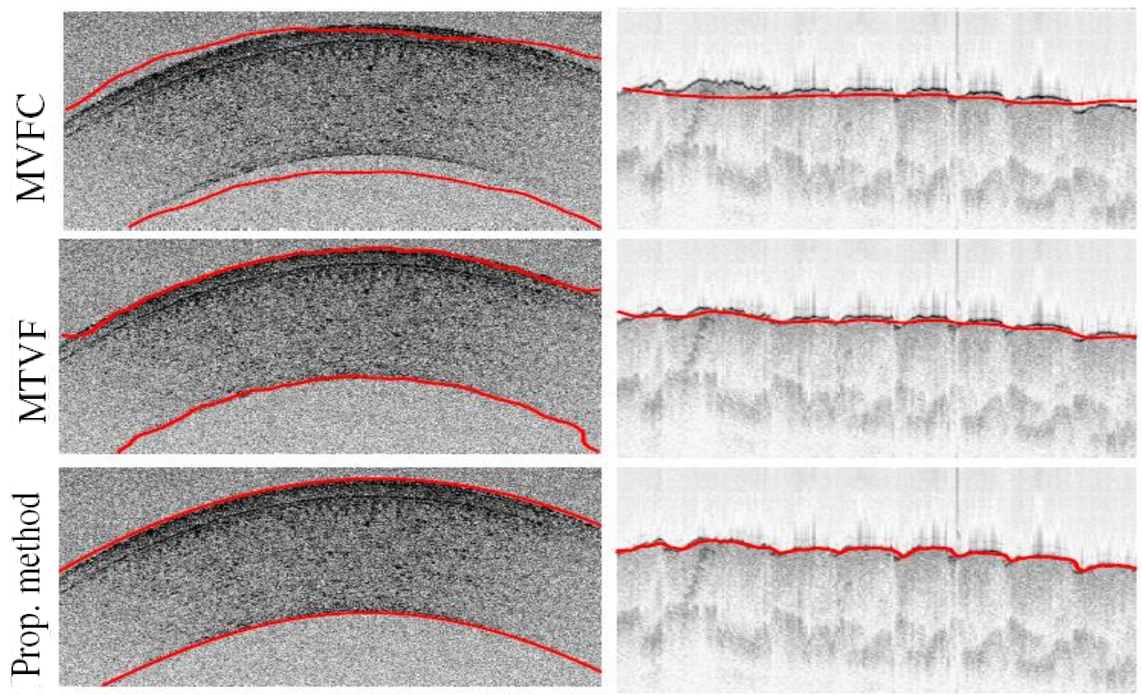

Fig. 5: The final segmentation results using the proposed method compared to the state-of-the-art methods of [2] and [3]

Method	Measurement	
	ASD	Jaccard
MVFC	18.1760	0.6989
MTFV	10.5156	0.86731
Proposed	**5.9108**	**0.9190**

Table 1: A performance comparison over a set of 16 OCT images.

Fig. 5 shows that the proposed method gives accurate segmentation compared to the state-of-the-art methods of [2] and [3] even with the high level of noise and the complex curvature. Table 1 shows a quantitative comparison, using a set of 16 OCT images, based on the Average Shortest Distance (ASD) and the Jaccard measures.

References

1. J.-L. Starck, J. Fadili, and F. Murtagh, “The undecimated wavelet decomposition and its reconstruction,”Image Processing, IEEE Transactions on, vol. 16, no. 2,pp. 297–309, Feb. 2007.

2. C. Yang and S.T. Acton, “External forces for active contours via multi-scale vector field convolution,” in Image Processing (ICIP), 2012 19th IEEE International Conference on, 2012, pp. 2569–2572.

3. A. Kumar, A. Wong, P. Fieguth, and D.A. Clausi, “Multi-scale tensor vector field active contour,” in Image Processing (ICIP), 2012 19th IEEE International Conference on, 2012, pp. 2557–2560.