Improved OCT Human Corneal segmentation Using Bayesian Residual Transform

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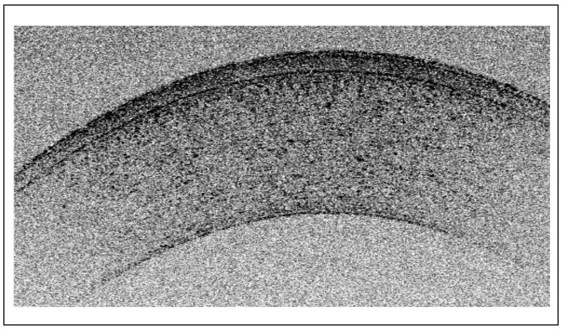
Abstract

The inherent poor signal to noise ratio of Optical Coherent Tomography (OCT) is considered as a main limitation of OCT segmentation, particularly because images are sampled quickly, at high resolutions, and in-vivo. Furthermore, speckle noise is generated by the reflections of the OCT LASER limits the ability of automatically segmenting OCT images. This paper presents a novel method to automatically segment human corneal OCT images. The proposed method uses Bayesian Residual Transform (BRT) to build a noise robust external force map, that guides active contours model to the corneal data in OCT images. Experimental results show that the proposed method outperforms the classical as well as the state-of-the-art methods.



Corneal OCT image

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.

1 Introduction

OCT is a visible light based imaging technique [1]. Compared to other modalities, such as ultrasound, X-ray and MRI which are relatively slow, use ionising radiation, or require a physical contact with the sample, OCT requires a short acquisition time and is a non-ionising radiation and contactless imaging technology. These attractive attributes make OCT more tolerant to sample motion, safer for long exposure times, and generally more convenient for patients [2][3].

However, as is clear from the images shown in Fig. 1, OCT images frequently suffer from a poor signal-to-noise ratio, particularly because images are sampled quickly and at high resolutions. This paper addresses the question of OCT images, segmentation, and scale. Since lower (finer) scales of OCT images contain details that are important for precise segmentation and coarser (higher) scales contain salient features that prevent speckle noise from deceiving the segmentation algorithm, our proposed method uses the BRT [4] as the basis for the energy function of the active contours.

Scale-space theory [5] and wavelet transform [6] have been extensively used in the fields of image de-noising and segmentation [7]. For instance, in [8], the wavelet phase representation of the image has been used as an external local cost, overcoming the problem of variations and non-uniform intensities in medical images. However, both scale-space theory and wavelet transform have their own limitations when used for noisy image segmentation. For example, the challenging process of selecting which scale represents the noise signal is a main limitation of scale space theory based methods. Moreover, wavelet transform based methods, especially when dealing with low SNR images, suffer from the oscillation artifacts related to wavelet basis functions. The ability of BRT to isolate the noise signal while preserving the inherent characteristics of the signal at low SNR, motivates us to use BRT as the basis for the energy function which constrains and pushes the active contours.

2 Bayesian Residual Transform

BRT models an input signal, $f(t)$, as the summation of n residual signals. Each characterizing different information from the signal at different scales:

$$f(t) = \sum_{i=1}^{n} r_i(t) = f_{\Sigma,1}(t). \quad (1)$$

where $f_{\Sigma,j}(t)$ is the summation of all residual signals at scales $[j,n]$:

$$f_{\Sigma,j}(t) = \sum_{i=j}^{n} r_i(t). \quad (2)$$

and r_i is the residual signal that characterizes the input signal information at ith scale. For the purpose of OCT image segmentation, BRT fine scales contain details that are important for precise segmentation, while coarser scales contain salient features that prevent speckle noise from deceiving the active contour model.

3 Improved External Force

Since BRT coarse scales contain salient information of the input signal, while fine scales contain fine details of the signal, our proposed method creates a weighted residual map that favors coarse scales over fine scales. Favoring coarse scales guarantees that the active contour is not caught by speckle noise or any other spurious features. The weighted gradient map $\Im$ is computed as

$$\Im = \sum_{i=1}^{n} 2^i r_i \quad (3)$$

The rationale for weighted map is illustrated in Fig. 2: clearly any number of scale-dependent weights could be proposed, however the figure shows a stronger signal to noise ratio in the weighted case. Furthermore the exponential scale-dependence of weighting coefficients is consistent with the scale-dependent behavior of wavelet coefficients in response to random and salient structure[6].

4 Experimental Results

This section compares the performance of this proposed method against classical as well as the state-of-the-art segmentation methods. The proposed method is compared against the classical Intelligent Scissors method [9] as well as one of the state-of-the-art multi-scale methods, namely the multi-scale vector field convolution (MVFC) [10] and the multi-scale tensor vector field (MTVF) [7]. Fig.3 shows that the high level of speckle noise in the underlying image prevents both [10] and [7] from locating the correct boundaries of the cornea. On the other hand, and due to the noise isolation feature of the BRT and coarse scale favoring, our method is able to correctly locate the correct cornea layers in the image.

5 Conclusion

In this paper, a novel method for automatic human corneal OCT images segmentation is proposed. The method uses the BRT transform to build noise robust external force maps, which drive active contour models to the desired image feature, namely the cornea boundaries. Comparisons against classical and state-of-the-art methods showed the superiority of the proposed method.

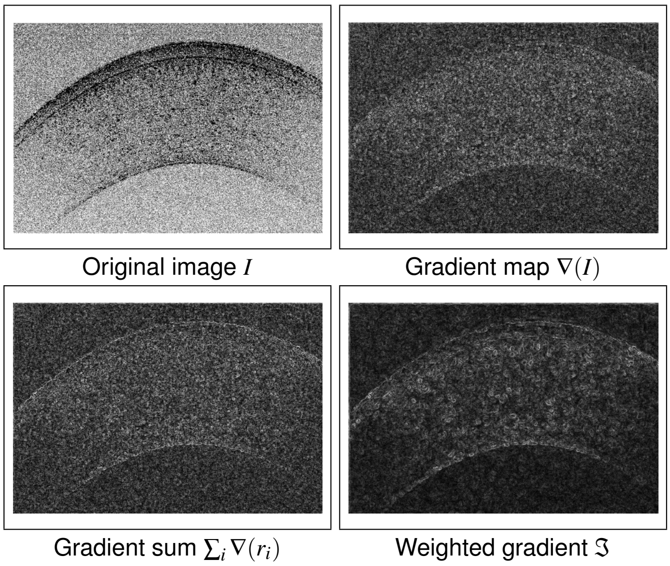


Fig. 2: The classical gradient map ∇I shows very little structure, essentially being overwhelmed by the high image noise typical of OCT. A sum of gradient maps computed over BRT scales gives a far stronger response; here the weighted gradient of (3), right, produces a stronger gradient than uniformly weighted, left.

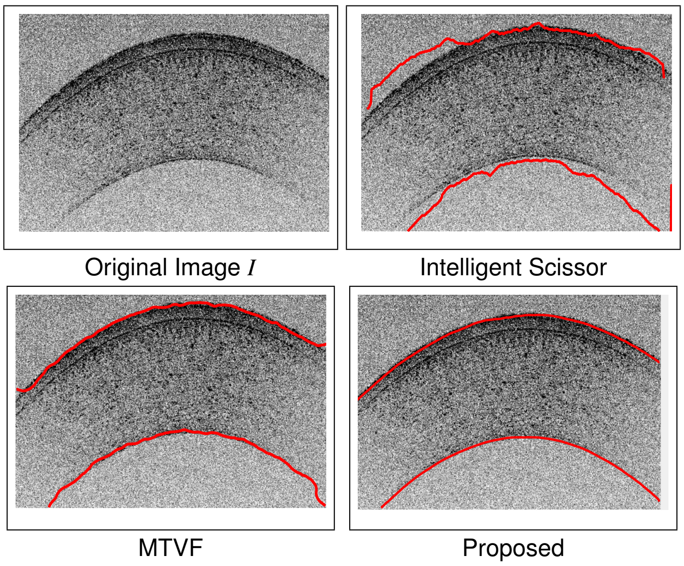


Fig. 3: A comparison of the proposed method, IS and MTVF. The proposed method outperforms all other methods.

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