International Journal of Modern Trends in Engineering and Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

Vessel Detection and Noise Suppression Methods of Optical Coherence Tomography (OCT) Images

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Abstract— Retina is the innermost layer of the eye and it has a layered structure, damage to any layer and variation in the layer thickness will cause loss of vision and lead to diseases such as Glaucoma, Diabetic Retinopathy etc. Thickness of the retina is measured by using the Optical Coherence Tomography (OCT). OCT is an imaging technique used for obtaining axial cross sectional images of translucent or opaque materials, such as biological tissues using a low-coherence light source. Images are corrupted by random variations in intensity values illumination, or have poor contrast called noise. In the proposed technique, an OCT image of eye is first cut into multiple vessel and non-vessel sections. Retinal blood vessels are detected through an iterative polynomial smoothing procedure. To suppress noise in the non-vessel sections various filters are used such as Gaussian filter, Wiener filter, Median filter, Average filter. From this paper we can conclude that median filter is suitable for noise suppression and this filtered image can be used for further processing such as segmentation and classification of retinal layers.

Keywords- Image Processing, Optical Coherence Tomography, Polynomial Smoothing, Vessel Detection, Filtering.

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I. INTRODUCTION

Optical Coherence Tomography (OCT) [1] captures back reflected light from tissue structure and provides cross sectional images. Imaging the cross-sectional retina by OCT is increasingly used for ocular disease diagnosis. Spectral domain OCT have higher scan speed, a better signal sensitivity, and a better definition of the retinal layers. Characteristics of spectral domain OCT are it contains a number of optical shadows of the retinal blood vessels which are brighter than the neighboring non-vessel sections, OCT images suffer from different types of noise such as the receiver noise which produces strong image variations from within retinal layers and many OCT images have little image variation across the layer boundary. Images suffer from different types of noise such as Additive noise, White noise, Salt and Pepper noise, Impulse noise, Gaussian noise, Speckle noise. The aim of de-noising is to take away the noise as collecting the imaging object information as much as possible to retain the important signal features of an image. This can be done by various filters such as Median filter, Wiener filter, Gaussian filter, Averaging filter. In OCT imaging technique the main drawback is the low quality of images, which are due to addition speckle noise in an image. Due to the presence of speckle noise it degrades image quality and it affects visual inspection to the doctors.

Accordingly, speckle filtering is the central pre-processing step for image quality enhancement in medical imaging techniques. Proposed technique performs Image Preprocessing, Vessel Detection and Filtering. Section II gives information about the database, section III describes image preprocessing and vessel detection and filtering, Experimental results are shown in Section IV and Finally, conclusion in Section V.

II. DATABASE

Proposed method used database from "H.V. Desai eye hospital", Pune and "National Institute of Opthmalogy", Pune using Topcon OCT machine. Information of the full depth scan can be acquired within a single exposure. We have worked on 50 images.

III. PROPOSED METHOD

This section describes Image preprocessing and Vessel Detection and the Different Filtering techniques to suppress the noise.

A. Image Preprocessing and Vessel Detection

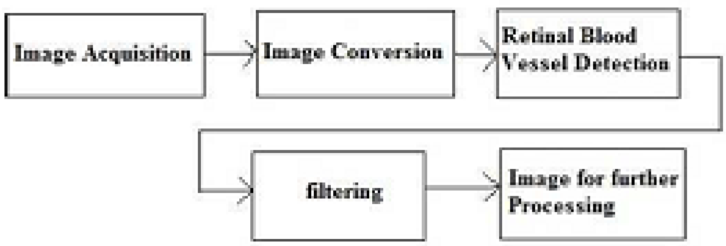


Figure 1. Block Schematic of Proposed Technique

OCT images of eye are collected in JPEG format from TOPCON OCT-1 Maestro Machine. fig. 2 original image is converted from RGB to grayscale image as shown in fig.3. Image preprocessing basically involves improvement or enhancement of image, which includes noise removal, highlighting, sharpening, deblurring, change in image contrast, masking, hair removal, cropping or resizing.

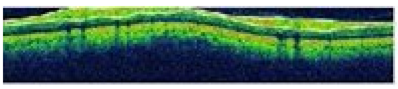


Figure 2. Input Image

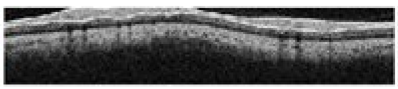


Figure 3. Gray Image

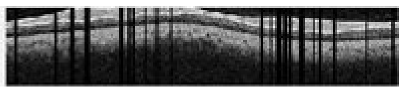


Figure 4. Vessel Section Detection

While measuring the layer thickness of retina, it is not possible to obtain layer thickness from blood vessels. Due to this reason, the blood vessels are identified before diagnosing the diseases. The order of polynomial is increased for different iterations. This step is required to identify all the blood vessels. The size of the window is determined so that minimum value can be identified for that corresponding window, as the value of blood vessels will be lesser than the non vessels. In this way blood vessel and non-vessel sections are detected in an image.

a) Mean Image Vector Calculation: Fig. 5(a) shows graph of mean light vector of gray image. The retinal blood vessels are detected based on the observation that the vessel sections are usually much brighter than the neighboring non-vessel sections [2]. Thus, the mean intensity of the image columns of the vessel sections will be much larger than that of neighboring non-vessel sections. This can be illustrated by the mean image vector as shown in Fig. 5(b) and (c) that is determined by the mean intensity of all image columns of the OCT image in fig.3.

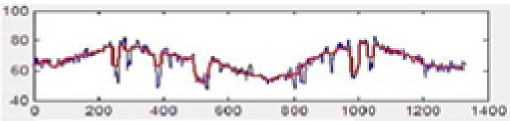
b) Polynomial Smoothing: As the retinal blood vessels are often of different widths, as shown in fig.3, we detect the retinal blood vessels through the polynomial smoothing of the mean image vector as illustrated in fig.4. To implement the polynomial smoothing, a number of equally separated points are first sampled. The data at each point is estimated by the median of mean image vector within a local window. The initial polynomial smoothing is set up as follows:

$$x_i = 1 + k_s i \quad (1)$$

$$y_i = f_{mdn}\left(I(x_i - k_s), \ldots, I(x_i + k_s)\right) \quad (2)$$

Where $i = 1, \ldots \ldots n$ and $I(x_i)$ is the element within the mean image vector at (x_i). Function $f_{mdn}(.)$ returns the median of the mean image vector within the local neighborhood window.
k_s is size of the neighbourhood window. The vessel sections can thus be located through an iterative polynomial smoothing procedure described in Algorithm.
Algorithm :
Step 1: Fit a polynomial P of order N (initial polynomial order) to all sampling data as specified in (1).
Step 2: Evaluate the maximum fitting error (defined below). Remove the sampling point with the maximum fitting error, if the error is larger than a predefined threshold T.
Step 3: Refit a smoothing polynomial P_i of order N_i as specified in (2) to the remaining sampled data.
Step 4: Repeat Steps 2 and 3 iteratively until the maximum fitting error is smaller than the predefined threshold or the remaining data points are smaller than $N_i + 1$.

Figure 5(a). Mean Light Vector



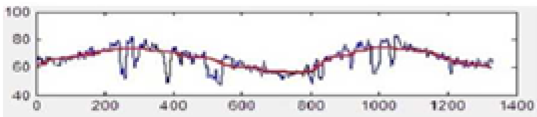


Figure 5(b). Initial Poly Filtered Light Vector ***Figure 5(c). Final Poly filtered Light Vector***

Figure 5. Bold graphs shows smoothing polynomials

The predefined threshold T specifies the maximum fitting error allowed and it can be set between 2 and 4 (the fitting error is the absolute difference between the sampled mean image intensity and the fitted smoothing polynomial shown in Fig.5. The bold and smooth graphs in Fig.5 show the smoothing polynomials fitted in different iteration, respectively. As Fig.4 shows, the polynomials fit closer to the mean image vector of the non-vessel sections during the smoothing process. The vessel sections can thus be detected through the global thresholding of the difference between the mean image vector and the final smoothing polynomial shown in Fig. 5(c). For the OCT image in Fig. 2, For the OCT image Fig.4 shows the detected vessel sections labeled by black blanks.

B. Filtering

1) ***Gaussian filtering****:* A Gaussian filter is a filter whose impulse response is a Gaussian function. It has no overshoot to a step function input while minimizing the rise and fall time and hence it has minimum group delay. This filter support in the time domain equally in frequency domain, it is linear low pass filter having minimum time-bandwidth product and very effective for removing Gaussian noise. Mathematically, a Gaussian filter modifies the input signal by convolution with a Gaussian function. In two dimensions, it is the product of two such Gaussians, one per direction:

$$g(x,y) = \frac{1}{2\pi\sigma^2} \cdot e^{\frac{-x^2+y^2}{2\sigma^2}} \tag{3}$$

Where x is the distance from the origin in the horizontal axis, y is the distance from the origin in the vertical axis, and is the standard deviation of the Gaussian distribution.

2) ***Wiener filtering****:* Wiener filter is a filter used to produce an estimate of a desired or target random process by linear time-invariant filtering of an observed noisy process, assuming known stationary signal and noise spectra, and additive noise. The Wiener filter minimizes the mean square error between the estimated random process and the desired process [3].

$$G(u, v) = F(u, v).H(u, v) \tag{4}$$

Where F is the fourier transform of an "ideal" version of a given image, and H is the blurring function.. Wiener filter is based on the least-squared principle, i.e. the filter minimizes the mean-squared error (MSE) between the actual output and the desired output. We get Wiener filtered output image as shown in fig.7.

3) ***Median Filtering****:* Median filtering is a nonlinear method used to remove noise from images. It is widely used as it is very effective for removing speckle noise and impulsive noise while preserving edges. The median filter works by moving through the image pixel by pixel, replacing each value with the median value of neighbouring pixels.

$$y[m, n] = \text{median } I[i, j], (i, j) \, \varepsilon w \tag{5}$$

where w represent a neighbourhood centered around location (m, n) in the image I with pixel value (i, j). Fig.8 shows Median filtered output image.

4) ***Average Filtering****:* Average (or mean) filtering is a method of smoothing images by reducing the amount of intensity variation between neighbouring pixels. The average filter works by moving through the image pixel by pixel, replacing each value with the average value of neighbouring pixels, including itself [5], [6]. For fig.5 we get Average filtered output image as shown in fig.9.

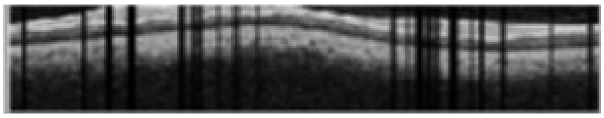


Figure 6. Gaussian Filtered Image

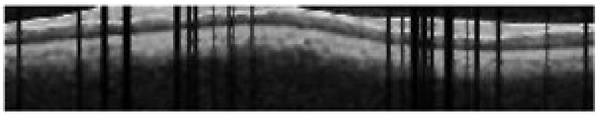


Figure 7. Wiener Filtered Image

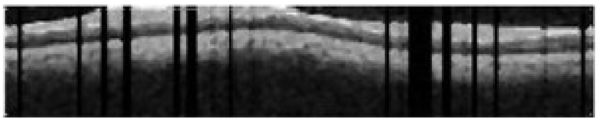


Figure 8. Median Filtered Image

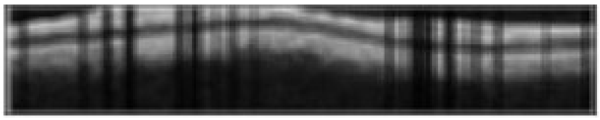


Figure 9. Average Filtered Image

IV. EXPERIMENTAL RESULTS

The performances for de-noising of images were tested on set of grayscale images with the resolution of 512*512. Objective evaluation and subjective evaluation is used to examine the quality of an image. For subjective evaluation, the image has to be observed by a human expert. There are various metrics used for objective evaluation of an image. Some of them are Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE) and Root Mean Squared Error (RMSE). RMSE is an estimator which gives information about by how much amount noisy image differs from noiseless image. PSNR is the ratio between possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Higher PSNR value provides higher image quality. Table I gives the comparison between different filters through the image metrics, PSNR, MSE and RMSE. A good filter shows higher PSNR, lower RMSE, which usually guarantees better subjective evaluation of the denoised image. Table I shows that median filter gives better result as compared to other filters.

$$PSNR = 10log_{10} \left(\frac{1}{MSE}\right) \ db \tag{6}$$

$$MSE = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}(\hat{f}(x,y) - f(x,y)^2)}{M*N} \tag{7}$$

$$RMSE = \sqrt{MSE} \tag{8}$$

Table 1. Calculated values of image metrics like PSNR, MSE and RMSE

	Gaussian Filter			Wiener Filter			Median Filter			Average Filter		
IMG No.	**PSNR**	**MSE**	**RMSE**	**PSNR**	**MSE**	**RMSE**	**PSNR**	**MSE**	**RMSE**	**PSNR**	**MSE**	**RMSE**
IMG1	21.38	473.13	21.75	24.22	245.77	15.67	19.80	679.53	26.06	18.58	900.04	30.00
IMG2	21.36	475.04	20.79	24.73	218.81	14.79	19.63	707.26	26.59	18.57	902.57	30.04
IMG3	21.34	477.38	21.84	24.59	225.58	15.01	16.89	1.38E +03	28.48	18.87	843.03	29.03
IMG4	23.75	273.59	16.54	26.92	132.02	11.49	21.09	505.45	22.48	20.95	521.80	22.84
IMG5	25.25	194.01	13.92	32.21	39.03	6.24	19.53	723.91	26.90	21.81	428.20	20.69

V. CONCLUSION

The proposed technique detects retinal blood vessels by using polynomial smoothing procedure and accordingly OCT image is split into multiple vessel sections and non-vessel sections. The non-vessel sections are then filtered by using different filters to remove the noise. Median filter gives higher PSNR and lower RMSE and hence it is used for smoothing because median filtering presents a significant reduction in noise while the edges are preserved better than other filters.

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