**Australian Journal of Basic and Applied Sciences**, 9(15) Special 2015, Pages: 166-171

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

# Retinal Layer Segmentation of Optical Coherence Tomography Images with Active Contour Model and Diffusion Map

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**ARTICLE INFO**

***Article history:***
*Received 10 March 2015*
*Received in revised form 20 March 2015*
*Accepted 25 March 2015*
*Available online 10 April 2015*

***Keywords:***
*Speckle noise, M-band wavelet filter, Active Contour Model,Diffusion map, Wiener filter, OCT,PSNR,SNR and MSE*

**ABSTRACT**

Ophthalmology necessitates automated segmentation of retinal layers in optical coherence tomography images to provide valuable disease information. This paper is focused on Speckle noise reduction and retinal layer segmentation. M-band wavelet filter is used for Speckle reduction of Optical Coherence Tomography (OCT) images.Comparison among Lee, anisotropic diffusion filter, Wiener, M-band wavelet filter is also made. M-band filter perform well in despeckling the OCT images.The performances of filters are measured with metrics such as Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR) and Mean Square Error (MSE). The retinal layers are segmented with a new segmentation method by combining Active Contour Model (ACM) and Diffusion map.



**To Cite This Article:** Srimathi M. and Usha A., Retinal Layer Segmentation of Optical Coherence Tomography Images with Active Contour Model and Diffusion Map***Aust. J. Basic & Appl. Sci.***, *9(15): 166-171, 2015*

## INTRODUCTION

Optical coherence tomography (OCT) is an established medical imaging technique that uses light to capture micrometer-resolution (better than 10 µm than other imaging modalities such as MRI or ultrasound), three-dimensional images from within optical scattering media.Speckle is a particular kind of noise which occurs in images obtained by coherent imaging systems like ultrasound. It tends to degrade the resolution and contrast of ultrasound images, thus may lead to eliminate some useful and important diagnostic information. The word ‘coherence’ in optical coherence tomography conveys both a primary strength and a primary weakness of this new technology. The coherence introduces speckle noise, an insidious form of noise that degrades the quality of OCT images. Speckle noise reduces contrast and makes boundaries between highly scattering structures in tissue difficult to resolve.

The neural retina contains the retinal progenitor cells (RPCs) that give rise to the seven cell types of the retina. Differentiation begins with the retinal ganglion cells and concludes with production of the Muller glia. Various types of diseases affects retina like Retinal detachment,Age related Macular degeneration, Diabetic retinopathy, Retinopathy, Retinopathy of prematurity,Hypertensive retinopathy, Cup disc ratio. Detection of diseased layer is feasible by imageprocessing. The retinal layers are described in detail as in Fig.1.

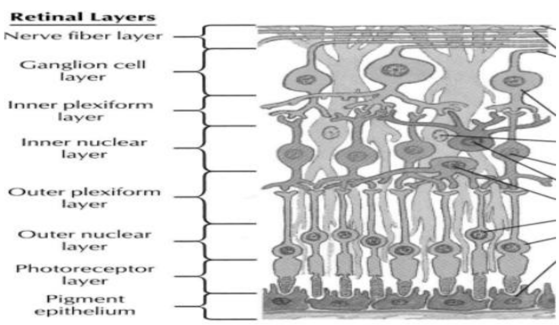


**Fig. 1:** Anatomy of Retinal layers.

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The following section involves Speckle noise and filters forreducing Speckle noise, Segmentation method, Algorithm flow, Results and Conclusion

***Speckle Noise:***

Speckle is a granular 'noise' that inherently exists in and degrades the quality of the active radar, synthetic aperture radar (SAR), and medical ultrasound images.This noise can be modeled by random value multiplications with pixel values of the image and can be expressed as,

$$J = I + n*I \quad (1)$$

where,

J is the speckle noise distribution image, I is the input image and n is the uniform noise image by mean0 and variance v. This noise deteriorates the quality of active radar and Synthetic aperture radar (SAR) images. Speckle noise is originated because of coherent processing of back scattered signals from multiple distributed points.

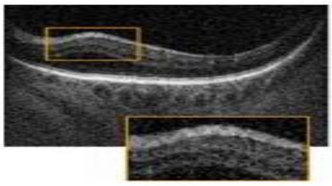

**Fig. 2:** Speckle noise in an OCT image of Retina.

***Filters For Reducing Speckle Noise:***

Several methods are used to reduce speckle noise, based on many mathematical models of the phenomenon.Filters such as Lee, Anisotropic diffusion, Wiener and M-band Wavelet Filter are taken for reducing speckle noise.

***Lee Filter:***

The Lee filter converts the multiplicative model into an additive model, thereby decreasing the problem of dealing with speckle noise to a known tractable case. The fundamental assumptions in their mathematical model,

- Speckle noise is a multiplicative noise, that is, it is in direct proportion to the local grey level in any area.
- The noise and signal are statistically independent of each other.

$$Y_{ij} = \bar{K} + W * (C - \bar{K}) \quad (2)$$

where, $Y_{ij}$ is despeckled image, $\bar{K}$ is the mean of the kernel/window, $W$ is the weighing function, $C$ is the center element in the kernel/window.

***Anisotropic diffusion filter:***

In image processing, anisotropic diffusion, also called Perona–Malik diffusion. It is a technique aiming at reducing image noise without removing significant parts of the image content, typically boundaries, shapes or other details that are important for the interpretation of the image. Anisotropic diffusion resembles the process that creates a scale space, where an image generates a parameterized family of successively more and more blurred images based on a diffusion process.

$$\frac{\partial I}{\partial t} = div(c(|DG_\sigma * I|)\nabla I) \quad (3)$$

where,

$G_\sigma = C_\sigma^{-\left(\frac{1}{2}\right)} \exp(-|x|^2/4\sigma)$, $G_\sigma$ is gradient operator, $\sigma$ is kernel size, I is input image, div is divergence operator, $C_\sigma$ is differentiation coefficient, D is Diffusion operator.

***Wiener filter:***

In signal processing, the Wiener filter is 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 reduces the mean square error between the estimated random process and the desired process.The input, x(t), to the Wiener filter consists of an unknown signal of interest, s(t), corrupted by additive noise, n(t)

$$x(t) = s(t) + n(t) \quad (4)$$

Although s(t) is unknown, it is known that x(t) and s(t) is correlated. The output, s(t), is calculated by means of a filter, g(t), using the following convolution,

$$s(t) = g(t) * x(t) \quad (5)$$

where, g(t) is the Wiener filter's impulse response.

***M-band Wavelet filter:***

For speckle noise reduction (Vosoughi, A,2008), first we need to model this particular kind of noise general model for speckle noise as,

$$f(x,y) = g(x,y)\, \varepsilon_m(x, y) + \varepsilon_a(x,y) \quad (6)$$

where, g(x,y) is the noise free image to be recovered, f(x,y) is the noisy image, $\varepsilon_m(x, y)$ and $\varepsilon_a(x,y)$ are multiplicative and additive noises respectively. The effect of additive noise is usually assumed to be small compared to multiplicative one and hence we assume $\varepsilon_a(x,y) \approx 0$ in equation (6).

$$f(x,y) = g(x,y)\, \varepsilon_m(x, y) \quad (7)$$

In order to convert multiplicative noise to additive one we apply the logarithmic transform to both sides of (7),

$$\log f(x,y) = \log g(x,y) + \log \varepsilon_m(x, y) \quad (8)$$

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***Performance Metrics For Despeckled Images:***
***Peak Signal to Noise Ratio (PSNR):***

PSNR analysis uses a standard mathematical model to measure an objective difference between two images. The PSNR block computes the peak signal-to-noise ratio, in decibels, between two images. This ratio is often used as a quality measurement between the original and a despeckled image. Higher the value of PSNR, better the quality of the despeckled image.

$$\text{PSNR} = 10\log_{10}\left[\frac{\text{MAX}_I^2}{\sqrt{\text{MSE}}}\right] \quad (9)$$

PSNR is Maximum possible pixel value to square root of MSE. MSE is to quantify the difference between values implied by an estimator and the true values of the quantity being estimated.

***Signal to Noise Ratio (SNR):***

The relationship between the signal and the amount of image noise present is expressed as the signal-to-noise ratio (SNR). Mathematically, the SNR is the quotient of the signal intensity measured in a region of interest (ROI) and the standard deviation of the signal intensity in a region outside the anatomy or object being imaged.

$$\text{SNR} = 10*\log_{10}\frac{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\hat{f}(x,y)^2}{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}[f(x,y)-\hat{f}(x,y)]^2} \quad (10)$$

where, f(x,y) is the Original image and $\hat{f}(x,y)$ is the despeckled image.

***Mean Square Error (MSE):***

PSNR is most easily defined via the mean squared error (MSE).

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j)-K(i,j)]^2 \quad (11)$$

where,I is a noise-free image of m x n and K is noisy approximation of I.

***Segmentation Method:***
***Active Contour model:***

The snake concept (Srikham,M.,2012), also called "active contour model", was originally introduced by Kass, in order to detect the boundary of an object in an image.

$$E(V) = E_{int}(V) + E_{img}(V) + E_{ext}(V) \quad (12)$$

where, V is a parametric curve, E is evolution driven by the minimization of an energy function, $E_{int}$ is internal energy,$E_{img}$is Image energy, $E_{ext}$is external energy.

The image energy attracts the curve toward thefeatures to be detected, such as edges or lines. The external energy ($E_{ext}$) can express additional contextual information. Thus, the curve is able to move dynamically from an initial position towards the desired boundary, without any further intervention.

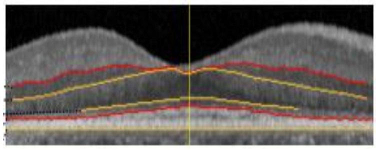


**Fig. 3:** Active Contour Model for segmentation.

However, some problems still remain. Especially, the snake is sensitive to the initialization and it is unable to converge to the correct solution in the presence of high levels of noise.

***Diffusion map:***

In signal processing approaches, most of graph based partitioning methods were based on time-domain analysis. It means that the graph partitioning was usually based on properties in the graph domain like gradient or texture. But newly developed methods in frequency domain are based on signal analysis in new domains (similar to Fourier transform in signal processing).

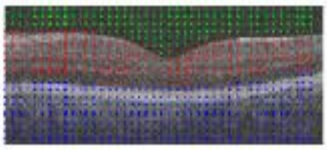


**Fig. 4:** Diffusion map on an OCT image.

In order to apply the diffusion maps to OCT images, graph nodes must be associated with the image pixels (Raheleh.,2013). We employ the diffusion map in 2 sequential steps, the first of which segments 5 layers simultaneously, i.e., the 1$^{st}$ and 7$^{th}$ to 10$^{th}$ layers. Each layer corresponds to a distinct anatomical structure. The second step identifies the inner layers, i.e., 2$^{nd}$ to 6$^{th}$ layers. This concept combined with active contour model now segments the retinal layers.

***Algorithm Flow:***

The filtering and segmentation process is carried out as follows, first an input retinal OCT image of size 1000 x 1050 pixels is chosen. By default the input image will have speckle noise, so as to reduce the speckle noise, the image has to be processed by the filter.

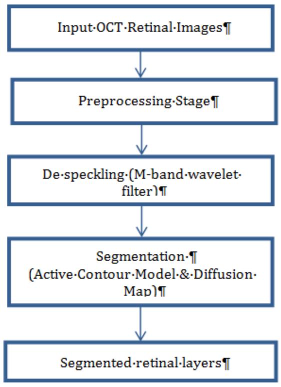



**Fig. 5:** Flow of Algorithm.

The despeckled image is passed to the segmentation stage, where the retinal layers are segmented to find out the diseased layers accurately. The segmentation stage contains the Active contour model and Diffusion map method.

***Results:***

An OCT image of retina is taken and processed with Lee, Anisotropic diffusion, Wiener and M-band Wavelet filter for despeckling.The despeckled output of filters is as,

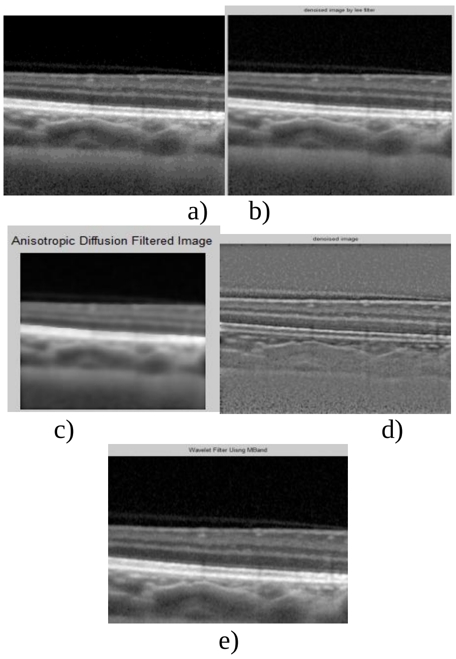



**Fig. 6:** Comparison of filtered images a)Original input image, output of b)Lee filter, c)Anisotropic diffusion filter, d) Wiener filter e) M-band Wavelet Filter.

The performance of each filter is evaluated for a single image, with metrics such as PSNR, SNR and MSE.Best filter is chosen among these filters after comparing their metrics.

The bar chart above shows clearly that M-band Wavelet filter results in good performance as shown in Fig.7

Table I shows the comparison of various filter performance metrics on retinal images. This work concludes that M-band Wavelet filter shows good result with high PSNR (dB).The results are well depicted in the bar chart Fig.8.

Table II and Table III shows the performances of different filters in terms of SNR (dB) and MSE.M-band Wavelet filter performs better than other filters.

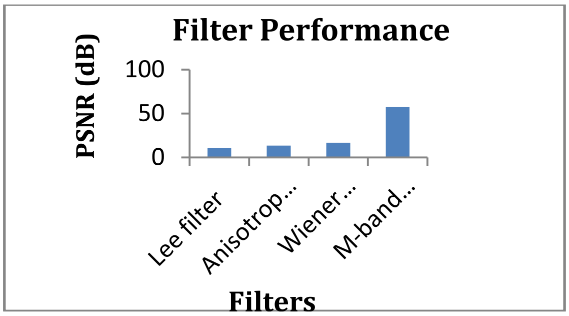



**Fig.7:** Bar chart for Filter performance.

**Table I:** Comparison Of Filter Performances On Retinal Images (Psnr In Db).

| OCT Input Images | PSNR(dB) | | | |
|---|---|---|---|---|
| | *Lee Filter* | *Anisotropic Diffusion Filter* | *Wiener Filter* | *M-band Wavelet filter* |
| Image1 | 13.211 | 15.917 | 16.045 | 60.737 |
| Image2 | 12.312 | 14.671 | 15.380 | 59.672 |
| Image3 | 14.800 | 15.762 | 15.800 | 61.066 |
| Image4 | 14.111 | 15.363 | 15.956 | 60.253 |
| Image5 | 13.099 | 14.557 | 15.023 | 61.541 |

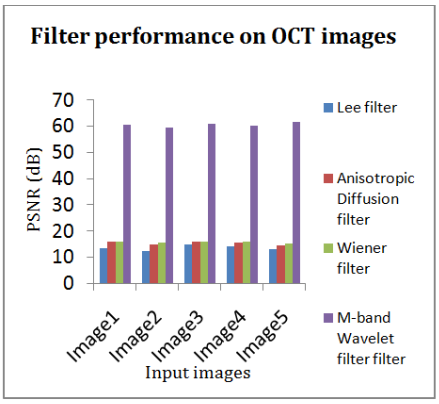



**Fig. 8:** Bar chart showing Filter performance on OCT images (PSNR in dB).

**Table II:** Comparison On Performance Of Filters (Snr In Db).

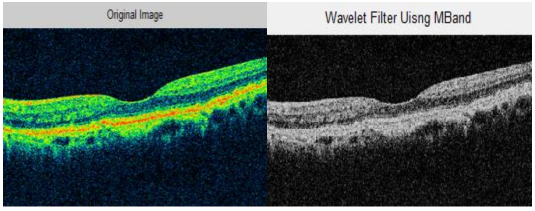
| Input Images | SNR(dB) | | | |
|---|---|---|---|---|
| | *Lee Filter* | *Anisotropic Diffusion Filter* | *Wiener Filter* | *M-band Wavelet Filter* |
| Image1 | 49.780 | 51.676 | 51.842 | 51.829 |
| Image2 | 51.188 | 50.089 | 51.546 | 51.776 |
| Image3 | 50.412 | 48.781 | 49.455 | 51.770 |
| Image4 | 51.580 | 49.842 | 51.001 | 51.763 |
| Image5 | 49.808 | 51.089 | 49.023 | 51.910 |

**Table III:** Comparison On Performance Of Filters (Mse).

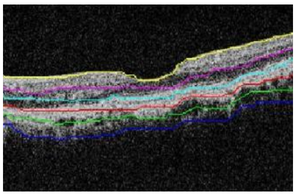
| Input Images | MSE | | | |
|---|---|---|---|---|
| | *Lee Filter* | *Anisotropic Diffusion Filter* | *Wiener Filter* | *M-band Wavelet Filter* |
| Image1 | 0.062 | 0.052 | 0.051 | 0.050 |
| Image2 | 0.058 | 0.056 | 0.053 | 0.051 |
| Image3 | 0.056 | 0.061 | 0.071 | 0.053 |
| Image4 | 0.065 | 0.073 | 0.063 | 0.060 |
| Image5 | 0.067 | 0.065 | 0.064 | 0.063 |

***Segmented Retinal Layers:***

The filtered image is then processed for segmentation of retinal layers by a proposed method. The proposed method involves combination of Active contour model and Diffusion map method. Active Contour model also called snake concept detects the edges in despeckled image whereas Diffusion map then segments the retinal layers as shown in Fig.9 c).




a) b)



c)

Fig.7 a) Original OCT image, b) M-band Wavelet filter output, c) Segmented retinal layer

***Conclusion:***

M-band wavelet filter works well in reducing the speckle noise among other filters. The performances of filters arefound with the metrics PSNR,SNR and MSE. Despeckled image is then taken for segmentation of the retinal layers withproposed active contour model and diffusion map method. These models help in segmentation of the diseased retinal layers accurately.

***Future Work:***

Proposed work involves calculating the thicknesses of each segmented retinal layers.

## ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Easwari Engineering College for their support andVasan Eye Care Hospital, Saidapet, Chennai for providing OCT images.

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