Diagnosis of Age Related Macular Degeneration by Curve Fitting RPE Layer

D Pavithra¹, R Vanithamani² and E Karolinekersin³

¹,²,³Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India

E-mail: pavithradharmaraj06@gmail.com, vanithamani_bmie@avinuty.ac.in, Karolinekersin_bmie@avinuty.ac.in

Abstract. Optical Coherence Tomography (OCT) of the retina allow high resolution and non-invasive imaging for diagnosis of macular diseases such as Age Related Macular Degeneration (ARMD). The aim of this work is to suppress the speckle noise, segment the retinal pigment epithelium layer and identify the possibilities for diagnosis of ARMD by curve fitting method. Speckle pattern, which is multiplicative in nature, degrades the quality of OCT images. Bilateral and homomorphic-wavelet filters are adopted to minimize the speckle noise in OCT images. The performance of these filters is tested on a set of OCT images collected from an open source database. The experimental results prove that homomorphic-wavelet filter is better in reducing the speckle noise. Structural changes of retinal pigment epithelium layer, a key factor of ARMD, is identified by Graph-based method, which is utilized further in diagnosis of ARMD by curve fitting method. The sum of square due to error (SSE) values of ARMD images are very higher compared to normal images, which can be used as a feature for diagnosis.

1. Introduction
Globally, ARMD is one of the prime causes of severe vision impairment in people over the age of sixty. In India, the prevalence of ARMD is around forty percent and it is expected to increase with the rise of population. It is also observed that the prevalence of ARMD is lower in subjects with diabetes and very much negligible in subjects with diabetic retinopathy. In ARMD, a specific part of the eye called macula undergoes progressive degradation due to ageing. There are two main categories namely neovascular and non-neovascular ARMD. Early stage of ARMD is usually non symptomatic, but leads to severe vision loss if left untreated. The main characteristic of non-neovascular ARMD is accumulation of extracellular aggregates called macular drusen which leads to Retinal Pigment Epithelium (RPE) abnormality. RPE is a pigmented retinal layer that nourishes the underlying cells of the retina and its most obvious function is light absorption. It improves the quality of image produced by optical system. RPE is liable to undergo several structural changes due to accumulation of age pigment lipofuscin, accumulation of basal deposits or basal infoldings. These useless residues disturbs the normal functioning of the optical system. Any structural changes to RPE layer degrades the image quality. Study of ARMD pathology using in vitro models have established that autophagy might play a central role in causing death of RPE cells and affects the retinal glial cells to some extent. It is also found that genetic factors has significant effect, as the descendants are more prone to ARMD if some of their ancestors had an experience of this disease. Anti-vascular endothelial growth factor therapy is a commercially available treatment for ARMD that improves or stabilizes vision in majority of the cases. Its key factors include early detection and better understanding of size and location of abnormality. OCT has become
a critical tool for baseline evaluation of retinal layers. As healthcare systems are vastly improving, automated screening tools can help ophthalmologists in diagnosis of ARMD at an early stage.

2. Related work
In the last decade, a large number of noise removal and segmentation methods have been developed for OCT images. Different researchers had diverse ideas about speckle noise reduction and segmentation of retinal layers which is discussed in this section. Padmasini N et al. (2014) utilized maximum fuzzy entropy principle for image enhancement followed by anisotropic diffusion filtering to suppress speckle noise in OCT images. Whereas, Naz S et al. (2016) utilized bilateral filter for de-noising and Ilyasova N et al. (2019) used Gaussian kernel with an optimum value of 3.5 for standard deviation as pre-processing step. Murakami T and Ogawa K (2018) proposed a transition invariant method to avoid artifacts at the corners of the block. Initially, the image was circularly shifted at four positions followed by wavelet decomposition using Daubechies kernel. From the de-noised image, pixel positions were relocated and averaged at each pixel position. Sui X et al. (2018) proposed a combination of wavelet-domain sparsity and total variation regularization that alleviates artifacts introduced by pure wavelet thresholding and preserves the edges of retinal layers while removing speckle noise. A common problem addressed in all these works was reduction of speckle noise. As the degree of diagnosis depends on better visualization of retinal layers, the second point discussed in this section is the segmentation techniques. Yang Q et al. (2010) gathered dual-scale gradient information using canny edge detection operator and then performed shortest path search using dynamic programming. This algorithm successfully segmented low intensity and low contrast OCT images in a very short time with good accuracy. Kafieh R et al. (2013) proposed diffusion mapping and k-means clustering with coarse graining for segmentation. This method relied on regional image texture through space-frequency analysis rather than edge information. Naz S et al. (2016) utilized thresholding for segmentation, polynomial curve fitting model to plot curve on RPE and their difference values are used as a feature to classifier for further diagnosis. Su L et al., (2017) compared different edge detection algorithms in segmenting retinal OCT images and suggested two pass method over canny and edge flow technique. Ilyasova et al. (2019) developed a graph based segmentation algorithm by constructing a minimum spanning tree of a connected weighted non-oriented graph and the retina vitreous-body boundary was identified with canny algorithm. De Moura J et al. (2020) identified four layers of the retina where it was subdivided into outer and inner retina. Adapting graph cuts and active contours are utilised for identification and the texture, intensity and clinical features are extracted using learning strategy. Regardless of the existence of general or partial proposals, this work aims to pre-process OCT images in order to reduce speckle noise using different filters and then segment RPE layer for further diagnosis.

3. Proposed Method
The proposed work aims to diagnose ARMD by curve fitting the RPE layer. A flow chart of proposed method is represented in figure 1. Noise removal techniques are discussed in Section 3.1, localization of RPE layer in section 3.2, followed by diagnosis of ARMD using curve fitting method in section 3.3. The images used in this work are taken from the dataset used by Srinivasan P P et al., (2014). This dataset consists of scans acquired from 45 subjects which includes normal, ARMD and diabetic macular edema using ‘Spectralis’ spectral domain OCT machine.
3.1. Speckle noise removal

An OCT image usually consists of speckle pattern which makes it convoluted to extort pathological features that can be utilized for further diagnosis. Hence, bilateral and homomorphic-wavelet filters are adopted as a pre-processing step to suppress the speckle noise associated with OCT images. The bilateral filter takes the weighted average of pixels and preserves edges by considering the variation of intensities alone. The bilateral filter replaces each pixel with its weighted value of neighbourhood depending on the geometric and photometric distance.

Homomorphic wavelet filtering involves the following steps. Initially, the natural logarithm of the input image is taken. Then it computes the wavelet transform, processes the wavelet coefficients followed by reconstructing the image using inverse wavelet transform. Since speckle pattern corresponds to the high frequency component of the image, which can be removed successfully. The exponential of the reconstructed image is the output of homomorphic wavelet filter. The resultant images of bilateral and homomorphic-wavelet filter are shown in figure 2. The performances of these filters are compared with the help of ten OCT images, whose Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR) and Structural Similarity Index (SSIM) are calculated. From Table. 1, it is clear that homomorphic wavelet filter removes speckle noise better than bilateral filter and hence, its resultant image is used in the forthcoming steps.

Figure 1. Proposed method

![Diagram]

Figure 2. Despeckled Images

(a) OCT image  (b) Bilateral filter  (c) Homomorphic-wavelet filter
Table 1. Evaluation metrics for Homomorphic-wavelet filter and Bilateral filter

| Image | Homomorphic-wavelet filter | Bilateral filter |
|-------|-----------------------------|------------------|
|       | PSNR(dB) | SNR(dB) | SSIM  | PSNR(dB) | SNR(dB) | SSIM  |
| 1     | 38.6177  | 27.6429 | 0.7035 | 29.0104  | 14.8425 | 0.6701 |
| 2     | 36.6364  | 26.8430 | 0.6707 | 28.2466  | 13.0292 | 0.5978 |
| 3     | 37.0047  | 26.5350 | 0.6940 | 29.0250  | 14.0405 | 0.5245 |
| 4     | 35.5692  | 24.0109 | 0.6095 | 25.9715  | 13.0096 | 0.6631 |
| 5     | 34.0034  | 23.9171 | 0.6130 | 25.0159  | 12.5961 | 0.4924 |
| 6     | 36.4364  | 26.3430 | 0.6607 | 28.2066  | 13.1252 | 0.5578 |
| 7     | 35.2672  | 24.1132 | 0.6435 | 26.1738  | 13.1226 | 0.5934 |
| 8     | 37.7147  | 27.9428 | 0.7014 | 28.9121  | 14.2407 | 0.6164 |
| 9     | 31.0034  | 22.2171 | 0.5930 | 24.4119  | 12.0947 | 0.4422 |
| 10    | 37.2347  | 26.7301 | 0.6847 | 28.3503  | 13.8445 | 0.5528 |

3.2. Localization of RPE layer
In order to localize the RPE layer, graph based method is adopted. First step is to calculate the graph weights and adjacency matrix. Then, gradient image is created as shown in figure 3(b). In OCT images, retinal layers are generally horizontal structures that are discernable by large variations in pixel intensity in the vertical direction. RPE layer is localized by getting the layer going from light to dark in the vertical direction using shortest path algorithm. As RPE layer is highly reflective, light to dark transition from gradient image can be clearly defined. First and last few points are discarded by assuming them as image borders. The resultant image is shown in figure 3(c), wherein the red line indicates RPE layer.

3.3. Curve fitting
Curve fitting is a process of constructing a curve over a series of data points. Its aim is to provide the best possible fit within the available data points and degree of the model. Here, the coordinates of localized RPE layer is considered and a very close curve is drawn over it using a second order Gaussian model. This curve fits correctly as a smooth curve on RPE layer of normal OCT, but doesn’t fit correctly on ARMD affected image due to uneven RPE layer (figure 4 and 5).
The SSE index which specifies the total deviation of response values from the input values are calculated as shown in eqn. 1, where \( w_i \) indicates weights, \( X_i \) indicates input values and \( Y_i \) indicates response values.

\[
SSE = \sum_{i=1}^{n} w_i (X_i - Y_i)^2
\]  

(1)

The plot of SSE values for 15 ARMD and 15 normal images are shown in figure 6. Since the curve cannot fit correctly, SSE values will be higher for ARMD images as compared to normal images. Therefore, curve fit model with SSE index can be used as a feature to diagnose ARMD.

4. Conclusion

In this work, an effective method for de-noising speckle pattern, localizing RPE layer and curve fitting method for diagnosis of ARMD in OCT retinal images is proposed. The graph based method successfully identified the RPE layer and curve fitting approach with discernable SSE index can be used to differentiate images with ARMD from normal images. This work will be a clinically useful tool to assist ophthalmologists in OCT-based ocular pathology identification and helps to improve the efficiency of retinal disease diagnosis. Future work will focus on segmenting additional layers and explore supportive feature extraction methods.

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