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MEASUREMENT OF RNFL THICKNESS USING OCT IMAGES FOR GLAUCOMA DETECTION

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Abstract

The thickness of retinal nerve fiber layer (RNFL) is one of the pompous parameters for assessing the disease, Glaucoma. A substantial amount of vision can be lost before the patient becomes aware of any defect. Optical Coherence Tomography (OCT) provides enhanced depth and clarity of viewing tissues with high resolution compared with other medical imaging devices. It examines the living tissue non-invasively. This paper presents an automatic method to find the thickness of RNFL using OCT images. The proposed algorithm first extracts all the layers present in the OCT image by texture segmentation using Gabor filter method and an algorithm is then developed to segment the RNFL. The thickness measurement of RNFL is automatically displayed based on pixel calculation. The calculated thickness values are compared with the original values obtained from hospital. The result shows that the proposed algorithm is efficient in segmenting the region of interest without manual intervention. The effectiveness of the proposed method is proved statistically by the performance analysis.

Keywords:

Optical Coherence Tomography (OCT), Glaucoma, Retinal Nerve Fiber Layer (RNFL)

1. INTRODUCTION

Glaucoma is a serious eye disease and the main cause for blindness worldwide. A watery material called aqueous humor is present in the eye. Normally it is produced by ciliary body and drained through canal of schlemm. If the drainage of aqueous humor is blocked, a pressure will develop in the eye. This increase in pressure destroys the cells and nerve fibers which prone to vision loss. Many diagnostic tests are available to find the types of glaucoma by assessing various parameters [1]. Among the parameters RNFL thickness plays a major role in finding glaucoma [2]. Diminished thickness of RNFL is an indication of glaucoma. A number of new and highly sophisticated image analysis systems are now available to evaluate optic nerve, RNFL and the areas of the eye damaged by glaucoma. OCT is one of the new and non invasive imaging techniques with better resolution and deep in penetration which shows its diagnostic capability [3]. Time domain OCT image is examined in this work for finding the RNFL thickness. It is a 3D imaging technique based on interferometry principle [4]. Although OCT measurement of RNFL thickness notifies information about the glaucoma status [5], the location of the OCT scan circle shall affect the measurement of RNFL thickness. Therefore, accurate registration of OCT scans for reproducibility, measurement and longitudinal evaluation is important [6].

2. PROBLEM FORMULATION

Dara Koozekanani et al. presented the retinal thickness measurements from OCT using a Markov boundary model. In this work, edge primitives are obtained from one dimensional edge detection kernel. Then the boundaries are detected by Markov boundary model which is further smoothened by cubic B-spline algorithm [7]. Hyohoon choi et al. presented the speckle noise reduction and segmentation on polarization sensitive optical coherence tomography (PS-OCT) images. In this work, wavelet de-noising method is used to reduce the speckle noise which is followed by fuzzy logic classifier for segmenting the RNFL. The classifier does not produce any satisfactory result in detecting lower boundary when compared to upper boundary detection of RNFL [8]. Delia Cabrera Fernandez et al. presented the automated detection of retinal layer structures on OCT images. In this work, structure tensor texture analysis and complex diffusion filtering are used. The proposed method results in better removal of speckle noise, enhancement and segmentation of various cellular layers of the retina [9].

Akshaya Mishra et al. presented the intra- retinal layer segmentation in OCT images. Here the individual layers are identified and segmented by means of two step kernel based optimization scheme. This proposed method is used to process and segment the OCT images with low contrast, speckle noise and irregular shape structural features [10]. Luzongqing et al. presented the variational approach to automatic segmentation of RNFL on OCT data set of the retina. Here the OCT data set is modeled as two probability density functions and the difference between these are described by symmetrized Kullback-Leibler distance. Then level set method is used to segment the RNFL with high degree of accuracy [11].

2.1 MATERIALS AND METHODS

The time domain OCT images used in this work are obtained from Aravind eye hospital in Pondicherry and also from Rajan eye hospital in Chennai. The Fig.1 shown below indicates the interpretation of OCT image [12].

Retinal nerve fiber layer is the first layer present in an OCT image which is shown in Fig.1. The layer thickness is calculated using MATLAB program that includes following steps.

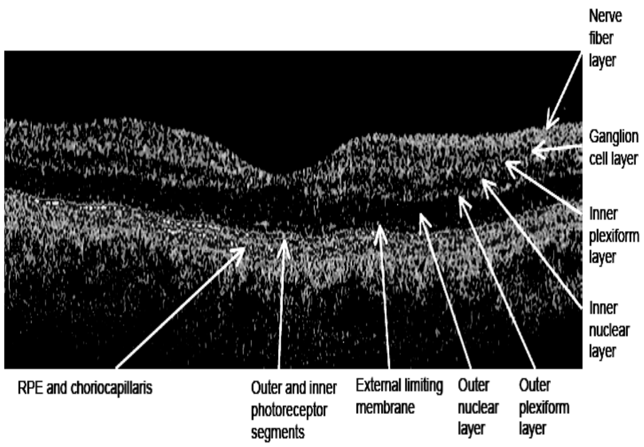

Fig.1. Interpretation of OCT image

2.2 IMAGE PROCESSING

First the input image is converted into grayscale image for further processing. This grayscale image is filtered by applying median filter in order to remove the speckle noise present in the OCT image. Speckle noise in OCT image can reduce its quality, diagnostic usefulness and also leads to difficulties in image interpretation. It is caused by coherent processing of backscattered signals from multiple distributed targets. Edges are most important for identifying the layers present in an image. Therefore filter selected for noise removal shall also satisfy the condition of edge preservation. Here median filter is preferred to remove the speckle noise due to its edge preserving nature.

2.3 IMAGE SEGMENTATION

Initially, Canny, Sobel, Laplace of Gaussian and Prewitt edge detectors are tried in finding the RNFL edges and it did not yield any progressive results. Then line detection using Hough transform is implemented by considering the boundaries as the lines. Similarly it also ended up with insignificant results. Finally image segmentation is preferred in this work. Here image segmentation includes texture segmentation using Gabor filter for segmenting all the layers present in an OCT image and a developed segmentation algorithm for extracting RNFL.

2.3.1 Texture Segmentation using Gabor Filter:

Texture property characterizes the nature of surface [13]. The process of texture segmentation using Gabor filter involves filter bank design, feature extraction of filter outputs and clustering in the feature space. These steps are explained below to determine the various layers in the image [14].

Step 1- Filter bank Design

Texture is defined as one or more basic local patterns that are repeated in a periodic manner. Two dimensional Gabor filters in the spatial domain could provide the exact localization of texture boundaries and is given by Eq.(1).

$$g_{\lambda\theta\psi\sigma\gamma}(x,y)=e^{-\left(\frac{x'^2+\gamma'^2y'^2}{2\sigma^2}\right)}\cos\left(2\pi\frac{x'}{\lambda}+\psi\right) \quad (1)$$

$$x'=x\cos\theta+y\sin\theta \quad (2)$$

$$y'=y\cos\theta-x\sin\theta \quad (3)$$

In this equation, λ represents the wavelength of the cosine factor in metres, θ represents the orientation of the Gabor function in degrees, ψ is the phase offset in degrees, γ is the spatial aspect ratio and σ is the standard deviation of the Gaussian. The spatial frequency of the cosine factor is calculated by taking reciprocal of the wavelength. Basically the Gabor filter is expressed as a function of Gaussian equation that is modulated by a complex sinusoid. This can explicit the sparse layer in the image.

Step 2 – Feature Extraction of Filter Outputs

Feature extraction is preferred to extract useful information present in the image. A non linear sigmoid function saturates the filter output which is given in Eq.(4),

$$Tanh(\alpha t)=1\frac{\left(1-e^{-2\alpha t}\right)}{\left(1+e^{-2\alpha t}\right)} \quad (4)$$

It is also necessary to find the average absolute deviation for each filtered output. Therefore each filter output is smoothened using a Gaussian smoothing function which is given by,

$$g(x,y)=e^{-\left\{\frac{x^2+y^2}{2\sigma^2}\right\}} \quad (5)$$

where, σ is the standard deviation.

Gaussian smoothing could increase the execution of segmentation when compared with the rest of the techniques by eliminating the difference in the feature that belongs to the same texture area.

Step 3 – Clustering in the feature space

The same texture features collected previously could form the layers in the image using clustering method. Pixel that belongs to same texture regions is clustered into groups in order to form the layers present in the image. This process utilizes basic k-means clustering algorithm to carry out automatic detection of number of clusters. At the beginning of process it initializes the centroids of k clusters in random fashion. Then it assigns each sample to the nearest centroid and calculates the centroids (mean) of k-clusters. The iteration will end if the centroids remain unchanged, otherwise it will again continue from assigning the sample.

2.3.2 Segmentation of RNFL:

An algorithm is developed to segment the RNFL from the texture segmentation output. Since it is the first layer in the image, the algorithm first searches for any change in the pixel value. This process will continue until an abrupt change in the pixel value is obtained. On occurrence of abrupt change in this process, the presence of an edge will be identified. The process continues again until another change is observed. At the instance of finding sudden change, the algorithm will stop the calculation process that leads to layer segmentation.

2.4 THICKNESS MEASUREMENT

Thickness of RNFL can be obtained by calculating the number of pixels in the RNFL. First the number of pixels in each column is calculated. Then the number of pixels in each column is multiplied with the resolution factor respectively. The resolution factor for OCT is 8 μ/pixel, a real-time value, obtained from the hospital. Finally the average of all the values is taken as the thickness of RNFL. This thickness measurement (T) is given by following equation,

$$T = \frac{\text{Resolution factor } * \text{No. of pixels in each column}}{\text{No. of columns}} \quad (6)$$

Resolution Factor = 8μ/pixel [for above Eq.(6)]

Using the above mentioned Eq.(6) the thickness of RNFL for both normal and abnormal images are calculated. There is no specific range for RNFL thickness and the variation is mainly due to the ageing factor of the patients. However RNFL thickness varies significantly with age [15].

3. PROBLEM SOLUTION

The results are obtained by processing the images by means of the above mentioned methods. The results include original image, gray-scale image, texture segmentation output image and segmented RNFL image and finally the thickness values. The outputs for one normal image and one abnormal image are shown below. Fig.2 to Fig.5 shows the original normal image, gray-scale image, texture segmentation output image and segmented RNFL image respectively. The corresponding results for abnormal image are shown in Fig.6 to Fig.9.

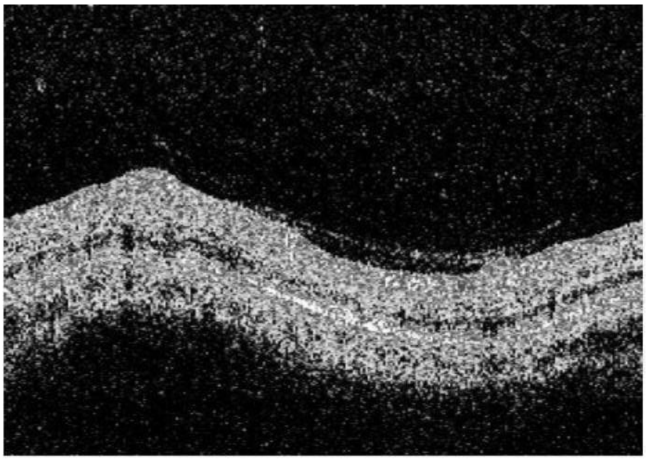

Fig.2. Original Image (normal)

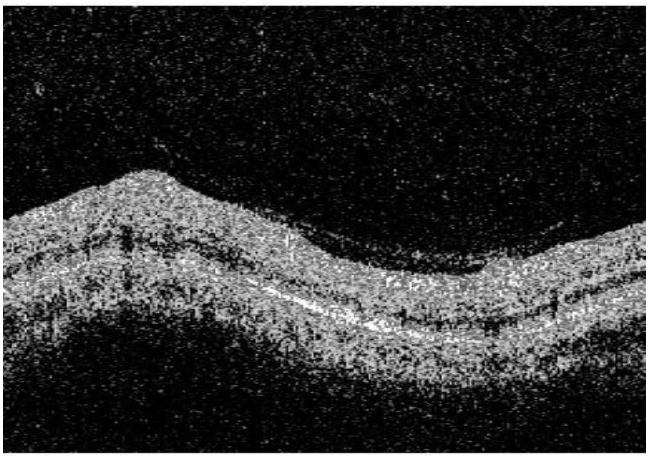

Fig.3. Grayscale Image (normal)

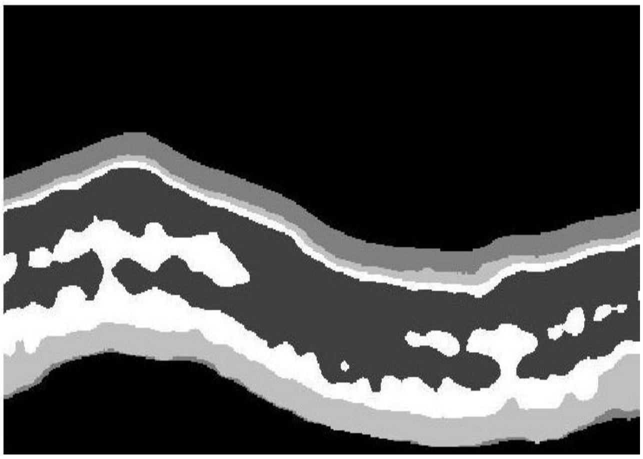

Fig.4. Texture Segmentation Output Image (normal)

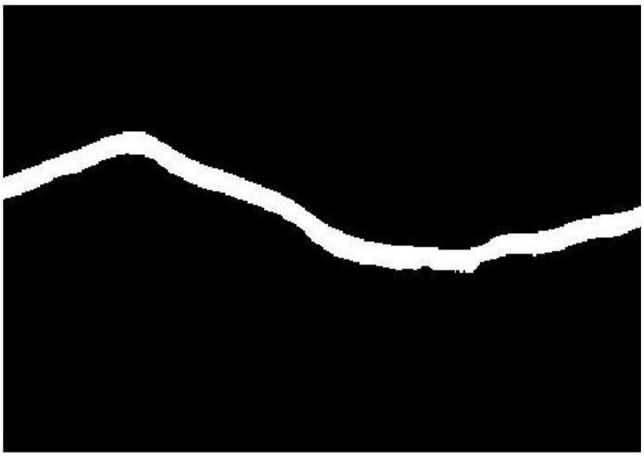

Fig.5. Segmented RNFL Image (normal)

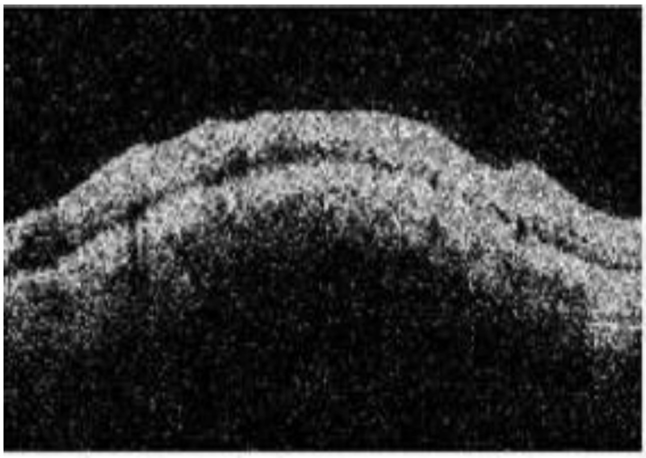

Fig.6. Original Image (abnormal)

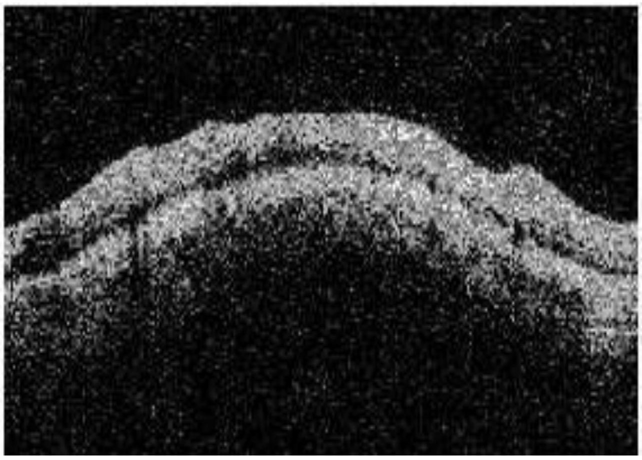

Fig.7. Grayscale Image (abnormal)

Fig.8. Texture Segmentation Output

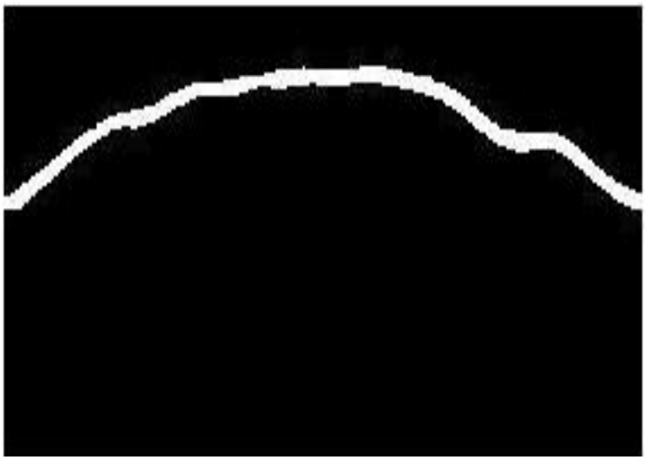

Fig.9. Segmented RNFL Image

Table.1. Thickness values of RNFL

Image	C_1 (μ)	C_2 (μ)
Normal1	175.96	171.32
Normal2	135.82	130.71
Normal3	158.2	165.37
Normal4	147.11	137.23
Normal5	131.63	135.78
Normal6	144.71	149.23
Normal7	123.63	129.89
Normal8	129.35	135.72
Normal9	141	149.23
Normal10	161.06	172.76
Normal11	109.1	109
Normal12	98.7	101
Abnormal1	109	99.21
Abnormal2	72.39	75.32
Abnormal3	90.03	85.42
Abnormal4	102.107	98.76
Abnormal5	63.9421	61.76
Abnormal6	62.79	59.37
Abnormal7	95.97	93.71
Abnormal8	102.87	92.67
Abnormal9	104.02	95.77
Abnormal10	89.61	87.52
Abnormal11	94.36	90.49
Abnormal12	99.21	90.76
Abnormal13	72.47	75.55
Abnormal14	76.29	77.69
Abnormal15	86.02	88.79
Abnormal16	108.702	97.65
Abnormal17	107.521	98.32
Abnormal18	100.96	94.76
Abnormal19	92.35	91.13
Abnormal20	92.3541	90.74
Abnormal21	63.3	58
Abnormal22	64.8	59
Abnormal23	69.8	69
Abnormal24	82.9	80
Abnormal25	86.3	77
Abnormal26	72.1	64
Abnormal27	99.7	93
Abnormal28	88.4	89.27

C_1- observed thickness values
C_2-gold standard values, μ- Unit in microns

The proposed algorithm is well suited for 40 out of 50 images and the thickness values of RNFL for both normal and abnormal images are tabulated above. The calculated RNFL thickness values (C_1) are obtained by using Eq.(6) and the expected RNFL thickness values (C_2) are obtained from the hospital. By comparing C_1 with C_2, it is observed that there is not any significant change in between them.

3.1 SCATTER PLOT

The performance of the proposed method is analyzed by means of scatter plot. Scatter plot shows the relationship between two variables by displaying data points on a two dimensional graph. From the scatter plot it is observed that the C_1 values and C_2 values increases simultaneously. This shows the existence of positive correlation. The scatter plot of RNFL thickness values are shown below in Fig.10.

$$\text{Pearson correlation of } C_1 \,\&\, C_2, (P) = 0.979 \quad (7)$$

$$\text{Regression equation is } C_1 = 12.1+0.904*C_2 \quad (8)$$

$$\text{Gold Standard} = -13.384+1.106*\text{Observed Value} \quad (9)$$

Minitab software is used here to obtain the scatter plot. Pearson's correlation (P) or Correlation coefficient (Eq.(7)) is a measure of strength of the linear relationship between two variables. The obtained correlation coefficient from the plot indicates the linear relationship between C_1 (Eq.(8)) and C_2 and the existence of positive correlation.

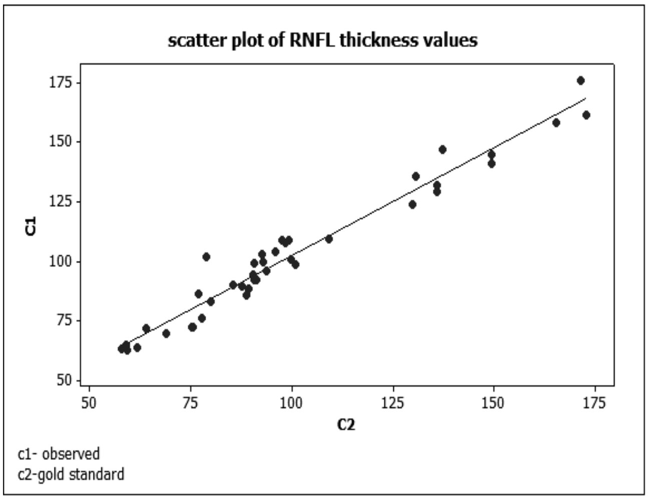

Fig.10. Scatter plot

4. CONCLUSION

In the proposed method, the thickness of RNFL is calculated for the detection of glaucoma using OCT images. In this work both normal and abnormal image are taken for the analysis. At first pre-processing is done by median filter in order to remove the speckle noise present in the OCT image. It is then followed by texture segmentation using Gabor filter for extracting all the layers in the image. Then the developed algorithm is used for RNFL segmentation leading to thickness measurement. The measured thickness values of RNFL are compared with the obtained real time thickness values obtained from the hospital. Although the changes are not significant, observed minor difference in values are still accountable and requires further analysis. This difference in values is due to the texture segmentation in which smoothing is one of the processing steps. Hence there is possibility of some information being lost in the images. However smoothing will improve the function of the segmentation process but excessive smoothing can have a negative effect on the localization of texture region edges. In the future, texture segmentation can be replaced by other advanced technique in order to segment the layers accurately. The proposed method is only best-suited for particular images which show its limitation. In order to improve the effectiveness of the proposed work, this can be implemented in spectral domain OCT which is a recent technique with high resolution [16].

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