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Retinal Nerve Fiber Layer Segmentation of OCT Images by Entropy Method.

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ABSTRACT

The present work provides a step by step approach for interpretation of accurate assessment of the optical coherence tomography (OCT) images and Retinal Nerve Fiber Layer (RNFL) morphology. The thickness of the RNFL decreased as the pressure increases that lead to Glaucoma. The RNFL is segmented by entropy method. The segmented RNFL is smoothed using Bezier curve technique. The inferior superior nasal temporal (ISNT) ratio shows changes in glaucoma condition. The algorithm is tested with 12 normal RNFL images and 45 RNFL images obtained from glaucoma patient. The result shows that the RNFL thickness for the set of normal images ranges from 88.2µm to 175µm and abnormal images ranges from 54.34µm to 99.35µm.
Keywords: Optical Coherence Tomography image, Retinal Nerve Fiber Layer, Glaucoma, Bezeir curve, Inferior Superior Nasal Temporal.

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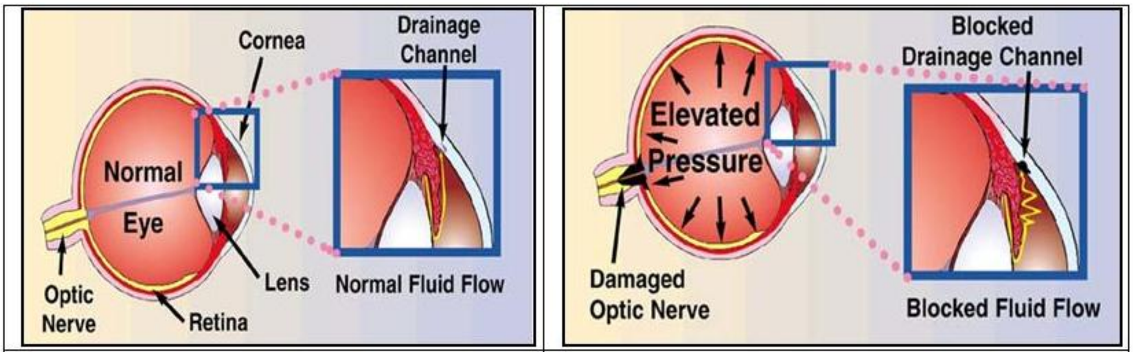
INTRODUCTION

Glaucoma is one of the common causes of blindness. It causes progressive degeneration of optic nerve fibers and leads to structural changes of the optic nerve and a simultaneous functional failure of the visual field. Since, glaucoma is asymptomatic in the early stages and the associated vision loss cannot be restored (Xiaoyang Song et al), its early detection and subsequent medical treatment is essential to prevent further visual damage. A watery material called aqueous humor is present in the eye, which is produced by the ciliary body and is drained through the Canal of Schlemm. If the aqueous humor does not drain out correctly, then pressure will build up in the eye. Figure 1(a) shows the normal fluid flow, which indicates the normal pressure that acts in the eye (George et. al). Figure 1(b) shows the blocked fluid which indicates the elevated pressure that acts in the eye. This high pressure damages the optic nerve leading to glaucoma. The retina is a part of the posterior segment of the eye and the retinal tissue consists of ten retinal layers. The light information detected by photo-receptors is processed by a variety of cells in different retinal layers and finally read out via ganglion cells. Axons of these neurons form the retinal nerve fiber layer (RNFL) and they exit the retina as a bundle in location called the optic nerve head (ONH) or the optic disc (OD).



(a) Normal fluid flow	(b) Blocked fluid flow (Chraste et al 2005)

Figure.1 Illustration of Glaucoma

Prior works

The visual information is delivered via the optic nerve into the brain, where the information is interpreted as an image. The glaucoma is characterized by degeneration of the retinal nerve fibers and is accompanied by an increased intraocular pressure. Loss of the nerve fibers results in decrease of the RNFL thickness. Then, the connection between the photoreceptors and the brain is progressively reduced and the patient loses his vision. 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. Hyohoonchoi 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. Delia Cabrera Fernandez et al. presented the automated detection of retinal layer structures on OCT images. In this work, ‘structure tensor texture analyses’ 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. 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 method is used to process and segment the OCT images with low contrast, speckle noise and irregular shape structural feature. 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 summarized Kullback-Leibler distance. Then level set method is used to segment the RNFL with high degree of accuracy. In the proposed system, a new algorithm is developed for RNFL segmentation by using entropy based texture method and Bezeir curve technique is applied to smooth the segmented RNFL. In addition with that the ISNT ratio is calculated which helps in strong prediction of glaucoma [1-12].

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The Proposed Algorithm

The flowchart of the overall scheme is shown in Figure 2

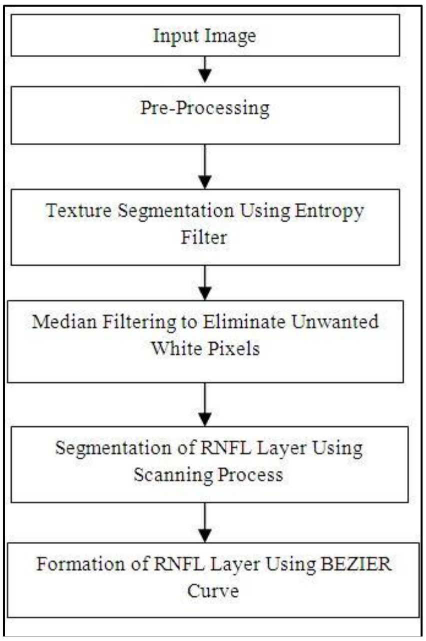

Figure 2: Flow chart of overall scheme

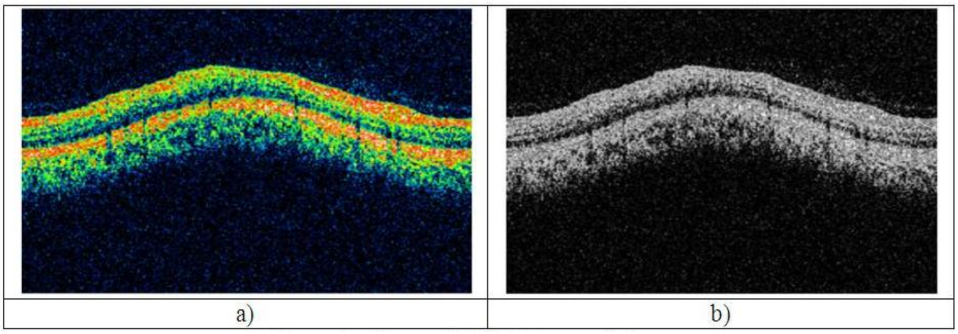

Figure 3: a) Input OCT b) Gray scale Image

Preprocessing

The input OCT RNFL image is converted into gray scale image as shown in the Figure.3a and Figure.3b. In this, the RNFL boundary is detected by transition of black pixel level to gray pixel level when the image is scanned from top to bottom. Since the presence of noise as bright dot affects the detection of RNFL boundary, the 2D median filtering is applied to reduce the noise and the Figure. 4 show the median filtered image.

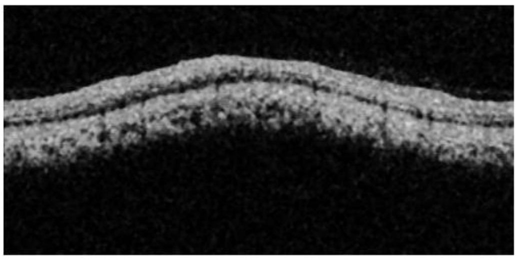

Figure 4: Median filtered image (abnormal)

Texture Filtering Based Segmentation

Earlier Canny, Sobel, Laplace of Gaussian and Prewitt edge detectors had tried to find the RNFL edges but they did not get any progressive result (Dhivyabharathi et al.). Then line detection using Hough transform is implemented by considering the boundaries as the lines, but it does not produce any significant result. Finally image segmentation is preferred to find RNFL edge. For segmenting all the layers present in an OCT image, entropy filter is used. The developed algorithm is used for extracting RNFL. The texture filter function uses several standard statistical measures to filter an image. It attempts to measure instinctive qualities described such as smooth, rough, silky or bumpy. The statistical measures could be range, standard deviation; entropy filter produces best output than the other. The range and standard deviation provides the local variability to the intensity of values to pixels in an image whereas entropy filter measures the statistical randomness in an image. The texture segmentation is done using entropy filtering technique so that the RNFL and the Retinal Pigment Epithelium layers are extracted as shown in Figure.5a and the output of the texture segmentation contains many unwanted pixels which are cleaned out using median filters as shown in the Figure.5b.

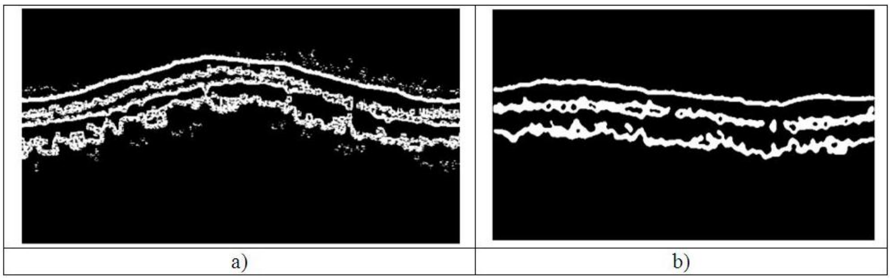

Figure 5: a) Texture segmentation output image (abnormal) b) Filtered texture segmentation image (normal)

Segmentation of Retinal Nerve Fiber Layer

An algorithm has been developed to segment the RNFL from the texture output. Since RNFL is the first layer in the image, the algorithm first searches for the change in the pixel value are obtained. When there is an abrupt change, then it indicates the presence of edge. When there is another change in the pixel value, the RNFL layer is obtained. Finally the image is scanned using column wise scanning technique in which occurrence of white pixels are scanned from the first column to the last column, as a result the required RNFL layer is obtained. This is shown in the Figure.6.

Figure 6: Segmented RNFL image

Bezier Curves

Bezier curves modeling technique is preferable than other modeling techniques (splines curves). The other techniques are not imperative and are constrained to pass through all the specified points. A Bezier curve section can be fitted to any number of control points. The number of control points to be approximated and their relative positions determine the degree of the Bezier polynomials. A Bezier curve is a mathematically defined curve used in two-dimensional graphic applications. The curve is defined by four points: the initial position and the terminating position (which are called 'anchors') and two separate middle points (which are called 'handles'). The shape of a Bezier curve can be altered by moving the handles. The mathematical method for drawing curves was created by Pierre Bezier in the late 1960's for the manufacturing of automobiles at

Renault. As with interpolation polynomials, a Bezier curve can be specified with boundary conditions, with a characterizing matrix or with blending functions. For general Bezier curves, the blending function specification is the most convenient. The Bezier curves can now be defined as a parametric function of the following form:

A Bezier curves of degree n defined by n+1 control points P0, P1, P2, Pn is

$$C(u) = \sum_{i=0}^{u} B_{n,i}(u)\, P_i \qquad 1 \leq u \leq 0 \tag{1}$$

Where the vectors $P_i$represent the n+1vertices or control points of a characteristic polygon$B_{n,i}(u)$, are the Berstein Polynomials which is defined as:

$$B_{n,i}(u) = C(n,i)u^i(1-u)^{n-i} \tag{2}$$

Where $C(n,i)$ is the familiar binomial coefficient,$B_{n,i}(u)$is the Bezier coefficients defined as

$$C(n,i) = \frac{n!}{i!(n-i)!} \tag{3}$$

ed and used to manipulate the curve intuitively. Transformations such as translation and rotation can be applied on the curve by applying the respective transform on the control points of the curve. In animation applications, such as Adobe Flash and Syn Figure, Bezier curves are used to outline the movement. Users outline the wanted path in Bezier curves, and the application creates the needed frames for the object to move along the path. For 3D animation Bezier curves are often used to define 3D paths as well as 2D curves for key frame interpolation. From the obtained segment of RNFL, using Bezier curve, the layers of RNFL is formed as it is shown in the Figure.7a. The layer that obtained is then superimposed with the original image and that is shown in the Figure.7b.

Determination of RNFL Thickness

Thickness of RNFL can be obtained by calculating the number of pixels. First the number of pixels in each column is calculated and is multiplied with the resolution factor (10 micros/pixels). Finally the average of all the values is taken as the thickness of RNFL. This thickness measurement is given by equation (4).

$$\text{Thickness in microns} = \frac{\text{Resolution Factor} * \text{Number of pixels in each column}}{\text{Number of Columns}} \tag{4}$$

Using the above mentioned equation, the thickness of RNFL for all the images is calculated. In this work, both normal and abnormal images are taken. Thickness value thus calculated is compared for both normal and abnormal images. This thickness of RNFL varies significantly with age. There is no any specific rage for RNFL thickness. The range of thickness varies accordingly for every patient and it depends upon the age of the patient.

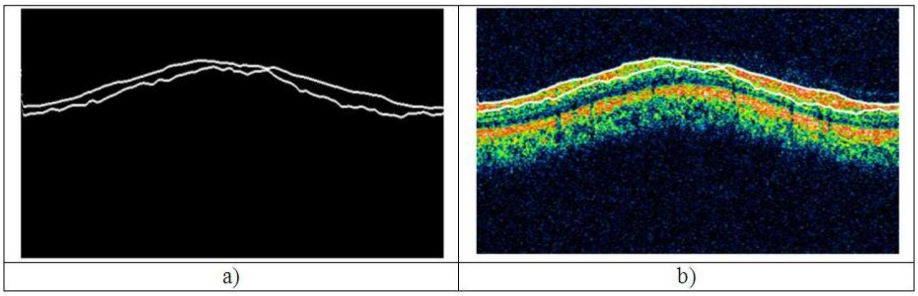

Figure 7: a) Smoothed RNFL using Bezier Curve and b) Segmented RNFL on the original Image

RESULTS AND DISCUSSION

The proposed algorithm is tested on 12 normal RNFL images and 45 RNFL images obtained from glaucoma patient.The result shows that the retinal nerve fiber layer thickness for the set of normal images

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ranges from 88.2µm to 175µm and abnormal images ranges from 54.34µm to 99.35µm. Figure 8a and 8b elicit the results by using both normal and abnormal subjects. Figure 9 shows the scatter plot computed with observed RNFL thickness and gold standard value as the parameters. The equation are relating these two parameters is given by

Gold Standard = 7.60 +0.890 Observed Mean (5)

Correlation Coefficient between observed value and gold standard is equal to **0.911**. In some of the images the extra regions are detected by the layer. This results in the correlation coefficient being less due to the error in the detection of RNFL images. The RNFL configuration is available for the diagnosis of glaucoma according to the ISNT rule. For a normal RNFL follows the property of decreasing thickness in an order of inferior, superior, nasal and temporal that is the inferior RNFL possesses the thickest portion and the temporal RNFL portion is the skinniest portion. Glaucoma frequently damages superior and inferior optic nerve fibers before temporal and nasal fibers and it leads to decrease the superior and inferior RNFL and change the order of ISNT relationship. Hence, the detection of RNFL distance in four quadrants can assist the measurement of ISNT rule and then improve the diagnosis of glaucoma at early stage. Figure 10a and 10b shows the normal and abnormal RNFL images respectively. The image which has lower ISNT ratio indicates glaucomatous eye whereas image which has higher ISNT ratio indicates the normal eye. The mean value normal and glaucoma ISNT ratios are 1.256 and 0.85006 respectively.

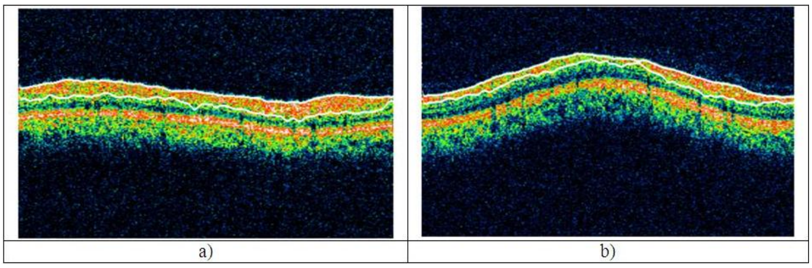

Figure 8: a) Normal Image and b) Glaucoma Image

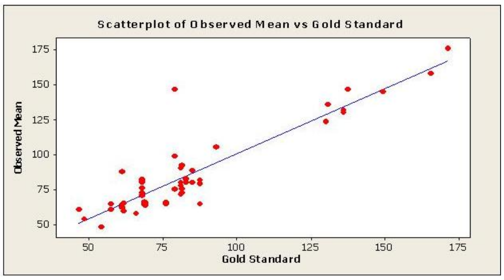

Figure.9 Scatter Plot of Observed Mean Vs Gold Standard

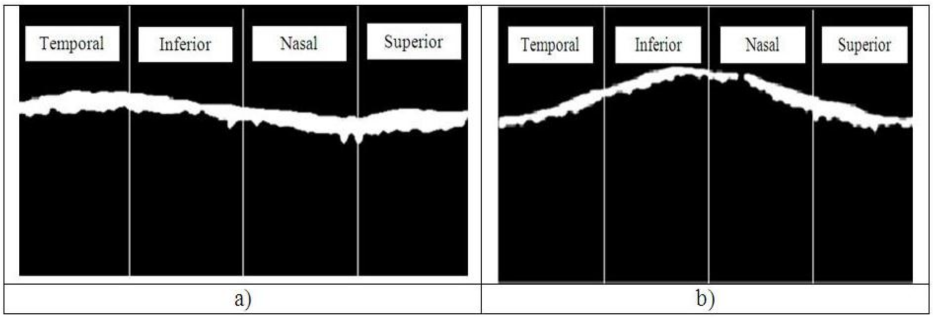

Figure 10: a) Normal Image and b) Glaucoma Image

CONCLUSION

The RNFL thickness is an important indicator of the risk of the presence of glaucoma in an individual. In this paper, we have presented a method to calculate the RNFL thickness from OCT image using texture based segmentation. After obtaining the RNFL boundaries, Bezeir curve step is introduced to smooth the obtained results. The ISNT ratios are determined from normal and glaucoma images. To determine the performance of our approach 57 RNFL OCT images are processed and their RNFL thickness is calculated. We have obtained the results for 57 images. The images that are utilized as database are obtained from Aravind Eye Hospital, Pondicherry, India.

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