EARLY DETECTION OF GLAUCOMA THROUGH RETINAL NERVE FIBER LAYER ANALYSIS USING FRACTAL DIMENSION AND TEXTURE FEATURE

Dharmanna Lamani[1], T. C. Manjunath[2], Mahesh M[3], Y. S. Nijagunarya[4]

[1]*Asst. Professor, Computer science & Engineering, SDMIT, Ujire, Karnataka, India,*
[2]*Principal, Electronics & Communication, H.K.B.K, Bangalore, Karnataka, India,*
[3]*Asst. Professor, Electronics & Communication, SDMIT, Ujire, Karnataka, India,*
[4]*Professor, Computer Science & Engineering, Tumkur, Bangalore, India,*

Abstract

The retinal nerve fiber layer (RNFL) is a vital part of human visual system, which can be directly observed by the fundus camera. This paper describes a method for glaucomatous retina detection based on Texture and Fractal description, followed by classification using support vector machine classifier. The color fundus images are used, in which the region of retinal nerve fibers are analyzed. It is shown that Texture & Fractal dimensions are correlated and linear correlation coefficient values are estimated at 0.35, 0.57, and 0.87 for healthy RNFL, medium loss and severe loss of RNFL respectively. The features are measured at 303 RNFL regions retinal positions in the peri-papillary area from 50 non-glaucomatous and 24 glaucomatous retinal fundus images. The presented method can also be used for glaucoma detection.

Keywords- *Retinal nerve Fiber layer, Glaucoma, Fractal dimension, texture feature, Box counting method*

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1. INTRODUCTION

Glaucoma is a second biggest retinal disease which leads to permanent blindness worldwide. The world health organization estimated 7.9 million people likely will get affected by the year 2020. Loss of retinal nerve fiber layer is the result of glaucoma disease. If not detected at initial stages, the retinal nerve fiber layer loss becomes permanent leading to blindness for the rest of life. Glaucoma cannot be cured through surgical means or medicines. At the most, ophthalmologist can provide treatment which helps to slowdown the progression of RNFL loss. Hence, early detection of RNFL loss is very essential for the ophthalmologists, in order to initiate treatment. The RNFL region is indicated as texture changes in color or grayscale retinal fundus images. But there is no efficiently used method for RNFL loss detection based on fundus images. Although an escalating effort in this area is noticeable [2, 4, and 5].

1.1 Background Work

The textural analysis of RNFL was performed on color fundus images by R. Kolar et.al. and the analyzed results were compared with RNFL thickness quantified by OCT. Here, the authors have performed the analysis and compared on normal subjects. This drives us to focus on defective subjects [1].Textural analysis of RNFL was also performed using Markov Random Fields. The atrophy of RNFL was described through feature vector extracted from Causal Autoregressive Random (CAR) model. A linear classifier was used to classify the defected RNFL and normal object with a classification error of below 4%.[2]. Fractal descriptions can also be a measure to detect RNFL loss. [4]. A model was built by M.A. Mayer et.al. using RNFL thickness and textural features extracted through segmentation [7]. Another kind of textural analysis was performed by A.Novatny et.al. which was based on local binary patterns and Gaussian Markov Random fields. In this work, RNFL was quantified and a classification error of about 3% was achieved [6]. A Glaucoma Risk Index (GRI) was introduced by R. Bock et.al. by combining a probabilistic 2-stage classifier and an appearance-based dimension reduction technique [17]. The quantification of RNFL was also done using three SD-OCT (Spectralis, Cirrus and RTVue) and one TD-OCT (Stratus). Despite high correlation among these instruments, RNFL values were significantly different between the instruments [16].

The identification and quantification of RNFL was simplified using Confocal Laser scanning Microscopy (CLSM) which provided enface and cross-sectional images of a whole mounted retina. [18]. E.Z Blumenthal et.al. assessed RNFL qualitatively using ophthalmoscopy, color stereophotography and re-free monochromatic photography. The quantification of RNFL was also done using Confocal Scanning Laser Ophthalmoscopy (CSLO), nerve fiber layer analyzer, OCT and Retinal Thickness Anayzer (RTA) [14].

Dhivyabharathi et.al. used Gabor filter for texture segmentation through which various layers were extracted from OCT images [9]. The algorithm proposed by the author segmented the region of interest efficiently without human intervention. This led to the measurement of RNFL thickness. These results were compared with those obtained from the hospitals. The appearance of speckle noise is due to the coherent processing of backscattered signals from multiple distributed targets. Speckle noise reduces quality and diagnostic usefulness of OCT images. Due to these issues, the interpretation of images will face difficulties. Also, edge plays an important role in identifying the layers present in an image. Hence, the authors finalized to use a median filter since it is characterized by edge preserving nature.

Cup-to-Disc ratio (CDR) is also an important parameter used in the diagnosis of glaucoma. CDR was always determined manually by trained clinicians. Hence C.B. Anusorn et.al. calculated CDR automatically from fundus images. To extract cup, color component analysis and threshold level-set method were evaluated. Whereas edge detection method and variational level-set method were used. An accuracy of 89% was recorded when these results were compared with those of clinical data [11].

The evaluation of retina through fundus camera is subjective and so efficiently reproducible. Whereas OCT allows quantification of RNFL directly and moreover the diagnostic procedures through OCT are reproducible. Apart from these merits, OCT diagnoses are expensive due to which they are not so widely available at many ophthalmic clinics. Hence, J. Odstrcilik et.al. have considered the faster and cheaper image acquisition using fundus camera. Through subjective analysis it was believed that variations in RNFL thickness led to changes in visual appearance of RNFL pattern. Later it was learnt that even in healthy retina, the variations of RNFL thickness anatomically was present which depended on the angular position around the ONH. These findings encouraged the authors to carry out analysis of RNFL variations through advanced image processing methods [2]. Hence we conclude that fundus camera images provide useful and easy-to-access information about RNFL which helps us to assess glaucoma through GRI or C/D ratio.

This paper describes a novel method to classify healthy RNFL, medium loss and severe loss RNFL using fractal dimension & texture feature properties. Section 2 presents the material and methodology with respect to RNF analysis. Section 3 briefly describes the pseudo-code and texture properties, & also discussed is the selection of features. Section 4 describes the result and discussion based on texture feature and Fractal Dimensions. Finally conclusion is put up in section 5.

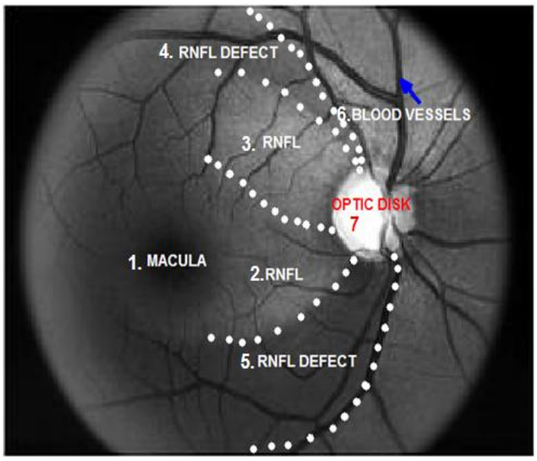


Fig 1 Retinal image from database showing macula, optic disk, blood vessels and region with/without retinal nerve fibers.

One of the images from database is shown in fig.1. It shows various regions of fundus. Region 1 is called macula which is oval in shape and is made up of two or more layers of ganglion cells. Regions 2 and 3 show healthy RNF layers. These regions are brighter as compared to regions 4 and 5. The latter two regions which are dark in nature show RNFL loss. Region 7 is the optic disk where blood vessels are accumulated. Also RNFL radiate from optic disk towards the macula. It is the RNFL which forms the optic nerve while leaving optic disk towards brain. The dark appearance of defected region of RNFL is due to its atrophy. The simple physics behind this is lowered reflection of incident light. The dark nature of RNFL in certain areas is not a reliable factor to conclude on glaucoma. Fig. 2 shows the fundus image in which certain areas enclosed by black squares depict healthy RNFL region. The white squared regions show RNFL losses. The textural features were extracted from these areas for analysis. A total of 101 healthy regions, 101 medium loss and 101 severe loss in RNFL were extracted from a set of 50 non-glaucomatous and 24 glaucomatous retinal fundus images.

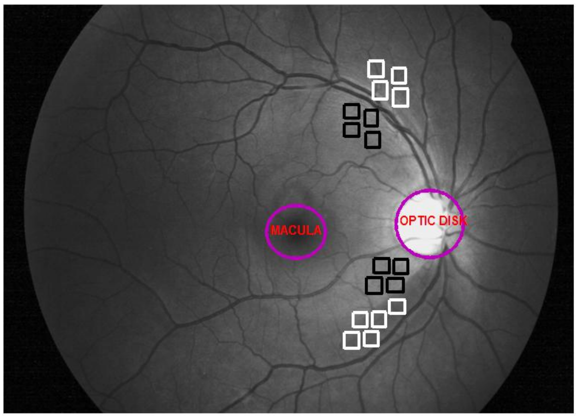


Fig 2 Detail of the fundus image. The dark squares show the samples taken for the fractal and texture features analysis from area of healthy RNF. The white squares show the samples taken for the fractal & texture features analysis from area of loss of the RNF.

2. METHODOLOGY

2.1 Material Used

The fundus images were collected from Shri Dharmasthala Manjunatheshwara Hospital, Dharwad (SDMHD), Karnataka, India. All images were captured with a resolution of 530 X 720 pixels. For experimentation, we have used 200 retinal images: 100 non-glaucoma and 100 RNFL loss images obtained from individuals of age group 25-56 years. Doctors in Ophthalmology department of the hospital certified image quality and usability. Fig. 1 & Fig. 2 represent the typical healthy (non-glaucoma) and RNFL damaged region retinal images. The fundus camera with microscope and light source were adopted to capture retinal images in order to diagnose glaucoma, neo-vascular glaucoma, macular degeneration, diabetes, etc.

2.2 Image Pre-Processing

Image pre-processing can significantly increase the reliability of a small neighborhood of a pixel in an input (I/p) image to get a new brightness value in the output (O/P) image. Such image pre-processing step consists of an image using normalization operator. Image normalization significantly increases the dynamic range of the histogram of the image. The intensity value in an input image includes a uniform distribution of intensity. As a result, the contrast of the image was increased. In second pre-processing step, Retinal nerve fiber layer loss retinal images are darker as compared to healthy RNFL retina. Hence we highlighted red channel component in the image for computation of fractal dimension.

2.3 Extracting Image Features

The extraction of image feature is explained through the flow chart shown in Figure 3.

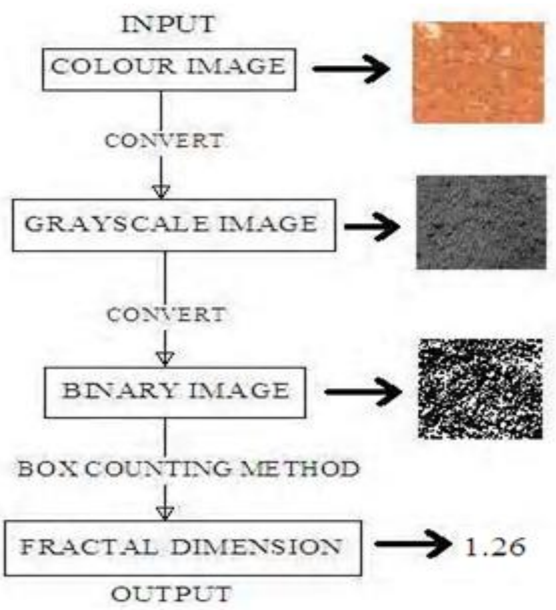


Fig 3 Flow Chart for Extraction of Image Feature

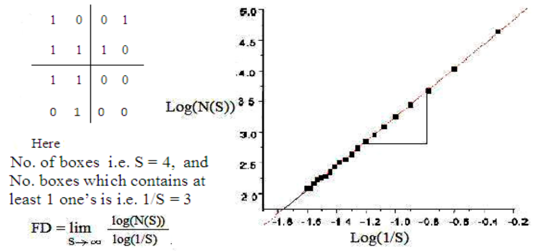


Fig 4 Box Counting Principle

2.5 Fractal Dimension

Fractal dimension allows us to measure the complexity of an object, that too preferably self similarity such as eye, brain, tree, mountain and so on so forth. Recently, Hsiao- Wen Chung et.al. presented fractal analysis approach for Nuclear medicine images for the diagnosis of Pulmonary Emphysema and concluded that FD seems to be an over simplified parameter unrelated to spatial heterogeneity of images [18]. Fractal analysis is potentially suitable for an objective quantification of spatial heterogeneity because it is believed to be effective in characterizing complex systems that are hard to describe using conventional Euclidean geometry. Fractal dimension is a parameter that can be determined solely by the image intensity [16].

2.5 Box Counting Method (BCM)

Box counting method is one of the most popular algorithms to determine fractal dimension of an image. Box counting method is described with the following example. The image was resized to gray scale image and was converted into binary image by bw method later to create square boxes, binary image was resized to a nxn so that the length, measured in number of pixels of a power of 2 this helps for the square image to be equally divided in to four sub parts and again each subparts divided in to four subparts and so on. The number of pixel which contains “white” pixels was recorded as function of the box size N(s), length of box. The reciprocal of box size is also noted as 1/r, this principle is repeated for all the binary images obtained by different threshold values ranging from 0.2 to 0.5 with interval 0.1 of an average binary retinal image. From figure 4, Number of boxes N(s) =4 number of boxes which contains ones N (1/s) =3. Hence fractal dimension =1.333.

2.6 Algorithm for Box Counting Method

The box-counting method was used on retinal images to exhibit a fractal structure. The image was resized to measure (256 × 256) and then converted into gray scale. Grayscale images became binary images with a threshold of 0.2 to 0.5 with distance of 0.1, meaning that if the pixel had a binary value greater than threshold (on a 0 to 1 scale) the pixel became “black”, or assigned the value of 0, otherwise if the pixel becomes ‘white’, then a value of 1 is assigned. The Algorithm developed for the box counting method as given below.1.26.(G) Texture analysis of RNFL in retinal images Various fractal dimension techniques were applied in our previous work [21, 22, 23, and 24]. Texture methods & statistical based techniques are common mathematical tools for texture classification. Hence these tools are employed for RNFL analysis. There are mainly three types of statistical techniques: first order statistics, second order statistics, and higher order statistics. In this paper, first order statistics is adopted, which depends on individual pixel intensity values, but not on pixels with inter relationship. The interpretations of parameters obtained through first order statistics are straight forward & provide a view on textural properties and its visual appearance. The various parameters of first order statistics are standard deviation, average, skewness, kurtoses, and shannon entropy etc. Among these parameters, mean and standard deviation are computed using intensity probability distribution (IPD), which is calculated from histogram of ROI. The detailed explanations of these parameters can be found elsewhere [1, 2]. The equations for parameters used in this paper are given in Table-1.

Table – 1: Mathemtical equation for Mean and SD

SL No	Features	Equation	Description
1	Mean	$u = \sum_{i=0}^{N} iH(i)$	H(i) denotes a PDF and is computed from histogram. H(i)=ni/N, where ni is the ith pixel for i=0,1,2….L-1, and N is the total number pixels. L is 255 (Gray levels).
2	SD	$\sigma = \sum_{i=0}^{N-1} (i-\mu)^2 H(i)$	

3. RESULT & DISCUSSION

The texture and fractal dimension features were extracted from each image sample: two features were estimated for all samples from each group (X, Y, and Z). The size of sample is 32 X 32 pixels. Which has been selected a sufficiently large region with RNFL striation. The upper limit of sample size was forbidden by the blood vessels & several other anatomical structures in the retinal images. First, the correlation coefficient is estimated for investigation. It is shown that Texture & Fractal dimensions are correlated and linear correlation coefficient values are estimated at 0.87, 0.57, and 0.35 for healthy RNFL, medium loss and severe loss of RNFL respectively, result shown in table 3. The result of correlation coefficient is put up in table 2, showing their linear dependency. The configuration was established based on hypothesis test with p-value < 0.01. In table-2, sample A and B belong to class X (severe loss of RNFL dataset). The sample C and D belongs to class Y (medium loss RNFL dataset). Finally, a sample E and F belongs to class Z (healthy RNFL dataset). Also, in table-4, statistical data such as mean, median, standard-deviation etc for fractal dimension and texture feature are depicted.

Figure 5 shows the plot of fractal dimension versus logarithmic values of texture features. Fractal dimension ranges from 1.01 to 1.72 and logarithmic mean texture feature ranges from 0.3 to 1.7 for dataset for class X. Fractal dimension ranges from 1.73 to 1.8399 and logarithmic mean texture feature ranges from 1.72 to 1.9 for dataset for class Y. Fractal dimension ranges from 1.84 to 1.99 and logarithmic mean texture feature ranges from 1.9 to 2.3 for dataset for class Z. Figure 6 describes sequence of operation performed to detect RNFL loss from region of interest of retinal image. Figure 6(a) shows RNFL loss retinal image and figure 6(b) is sample of the RNFL loss which is considered for the estimation of mean texture feature and FD. Mean texture feature is computed by equation 1 which is given in table 1. Whereas fractal dimension estimated from figure 6(c) that is 1.6357.

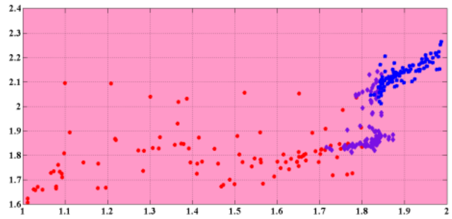
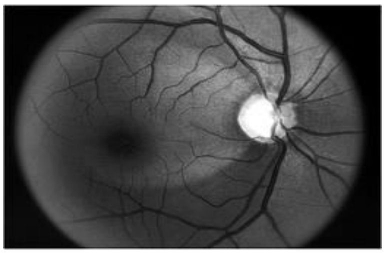
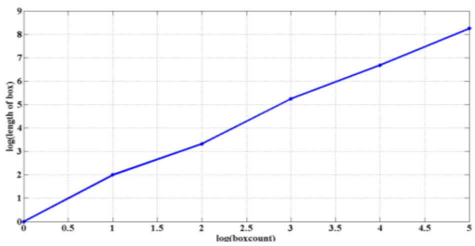


Fig. 5: Graph of FD versus logarithmic mean of ROI (ln(μ))



(a)

(b)



FD=1.6357, μ =47.7477) , ln(μ =2.34

(c)

Fig. 6: (a) RNFL loss retinal images, (b) RNFL loss ROI and mean μ=47.7477, and (c) Fractal Dimension 1.6357

Table 2: The table summarizes the Spearman's correlation coefficients computed from samples in particular image. The mean value and fractal dimension values are presented. (Sample A & B belongs to Class X, Sample A & B belongs to Class Y, and Sample A & B belongs to Class Z).

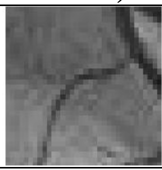
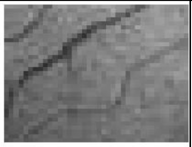
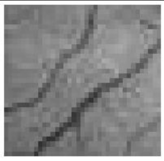
						
	A	B	C	D	E	F
FD	1.4256	1.6734	1.7234	1.8091	1.8450	1.8444
μ	52.2525	66.4525	81.4521	116.5927	123.3822	118.6125
ln(μ)	1.7281	1.8225	1.9092	2.0666	2.0912	2.0721

Table 3: Spearman correlation coefficients between texture and fractal dimension features for the whole dataset; p value < 0.01

Classes	Class X	Class Y	Class Z
Correlation	0.35	0.57	0.87

Table 4: Statistical data shown for ROI of healthy RNFL tissue, Medium RNFL loss, and severe RNFL loss.

SL. No	Attributes	Healthy RNFL (class X)		Medium loss (class Y)		Severe loss (class Z)	
		FD	μ	FD	μ	FD	μ
1	Mean	1.465	1.805	1.817	1.921	1.894	2.13
2	SD	0.2473	0.1021	0.03075	1.869	0.04515	0.04954
3	Range	0.8276	0.4867	0.1574	0.3299	0.1661	0.2535
4	Median	1.51	1.794	1.825	1.869	1.88	2.131
5	Mode	1.012	1.608	1.845	1.812	1.844	2.011
6	Min	1.02	1.608	1.716	1.812	1.821	2.011
7	Max	1.839	2.094	1.873	2.142	1.987	2.264

4. CONCLUSION

In this paper, authors presented a solution for retinal nerve fiber layer loss estimation using fractal dimension & texture feature, in order to early detection of glaucoma progression. This method is contrast to earlier approaches which have mainly considered on the computations of cup-disk ration (CDR) which varies considerably within normal's and also detects glaucoma after 40% RNFL loss. The presented work enables more comprehensive assessment of the retinal nerve fiber layer and performing glaucoma detection using RNFL loss determining through fractal dimension and texture feature.

Spearman correlation co-efficient estimated for FD and texture feature for healthy, medium loss, and severe loss RNFL are 0.85, 56, and 35 respectively. The proposed features can be used as a part of feature vector in glaucoma risk, as explained in [1]. These features may be also used in the glaucoma screening program together with other features such as CDR, ISNT ration, and RNFL thickness etc. based on different methods [5, 6, and 7].

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