Retinal Nerve Fiber Layer Analysis in Digital Fundus Images: Application to Early Glaucoma Diagnosis

Dharmanna Lamani, T.C. Manjunath, M. Mahesh and Y.S. Nijagunarya

Abstract Glaucoma is a second biggest eye disease which leads to permanent vision loss. The present day glaucoma diagnosis includes analysis of cup-to-disk ratio and detection of retinal nerve fiber layer (RNFL) loss. Glaucoma detection using cup-to-disk ratio approach is possible only after 40 % of vision loss. Also, OCT instruments are not widely available in all hospitals due to the cost factor, thereby making them a costly approach. In this paper, fundus images are considered for texture property analysis. Texture properties of RNFL region are analyzed using image-based fractal dimension (FD) feature and gray level co-occurrence matrix method (GLCM). Positive correlation coefficient is achieved for FD and contrast property of GLCM. Such analysis of texture property involving RNFL on fundus images lead to low cost and early diagnosis of glaucoma.

Keywords Glaucoma · RNFL · GLCM · Fractal dimension · Contrast

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Introduction

Reports from world health organization (WHO) suggest that over 5.2 million people are blind due to glaucoma. This statistics show a noticeable share on the causes for blindness across the globe. Unlike OCT images, ophthalmoscopes' images are analyzed in a faster and cost-effective manner. Ocular fundus images are used as a tool for diagnosis of many retinal diseases such as primary and secondary glaucoma. Analysis of cup-to-disk ratio, intra ocular pressure, and neural rim area lead in to detection of glaucoma. But the retinal nerve fiber layer (RNFL) loss, if analyzed, may be very productive in the early detection of glaucoma so that clinicians may initiate the treatment to control the progression of glaucoma. Figure 1 shows one of the images from our database with RNFL loss. Major components of retina are also noted in this figure: prominently one healthy RNFL area and two areas with RNFL losses. Optic disk (OD) is a section where blood veins and retinal nerve fibers (RNF) are concentrated. Macula is another important region with the highest concentration of retinal ganglion cells (RGC). The RNFL is placed in between OD and macula. RNFL loss can be quantified by extracting features from fundus images. Many authors have worked in order to detect and quantify the changes in RNFL thickness.

Literature Review

The variations due to atrophy of RNFL were analyzed by Jan Odstrcilika et al. [1] through a method which used Gaussian random Markov fields and local binary patterns. Apart from these, a few regression models were also designed to quantify RNFL thickness. The results were correlated with those obtained through OCT. Cup-to-disk ratio was calculated with the aid of detecting edges and exploitation of

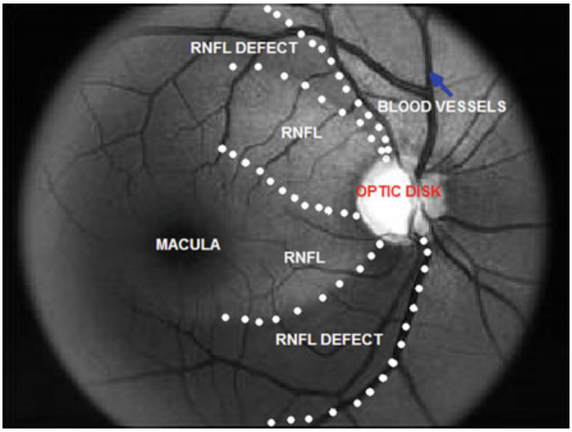


Fig. 1 Retina with healthy and damaged part of the retina

variational level set method by Chalinee Burana-Anusorn et al. [2]. The results obtained through the proposed method were compared with the readings of ophthalmologists achieving an accuracy of 89 %. A segmentation algorithm was proposed for frequency domain data of RNFL on OCT scans of healthy and glaucomatous retina [4]. The authors minimized the energy function which comprised of local smoothing terms and the gradient. This automated segmentation procedure was compared with those of three manual corrected segmentations. The authors considered 72 scans of glaucomatous and 132 scans of healthy retina in order to evaluate the segmentation procedure. The authors achieved 2.9 μm of mean absolute error per A scan over the set of glaucomatous retina, whereas 3.6 μm on the set of healthy retina. A dimension reduction technique based on appearances was considered to compress various features of fundus images [5]. A classifier comprising of double stages was designed using probability theory to extract the risk index which showed the performance of detection of unhealthy retina. The RNFL was quantified by Xiang-Run Huang et al. [6] using confocal laser scanning microscopy. Fluorescent stains were used to detect the nerve regions. The obtained results were not compared with those of clinicians' measurements. Such issues drive us to quantify RNFL in a novel manner and correlate them with the data obtained from clinicians. Stokes parameters were calculated by Park et al. [7] to quantify RNFL. The fast axis of the retina was also found. Finally, phase retardation of RNFL was estimated. A bilateral filter was used to extract non-vessel regions from the retinal blood vessels [8]. Hence the boundaries were detected and thus segmentation was achieved. A probabilistic model was designed to make sure that OCT scans on the vessel regions of retina [9]. Data acquisition was achieved for better reproducibility. An accuracy of over 91 % was achieved in the detection of glaucoma when the texture and higher order spectra features were used with random forest classifier [10].

The present article is organized in the following sections. Section "Introduction" presents RNFL loss leading to glaucoma along with review of previous works. Section "Dataset" describes retinal image database and preparation of class A and class B samples containing healthy and unhealthy (RNFL loss) RNFL regions. Section "Methodology" presents methodology of the present work. Section "Result and Discussion" demonstrates results and discussion, and section "Conclusion" includes conclusion of work.

Data Set

This section describes about preparation of database and retinal sample data in subsection A and B, respectively.

Database

The database is prepared using state-of-the-art technique. Our retinal database consist of 24 colored images of glaucoma affected retina with significant loss in RNFL and 10 colored images of healthy retina. The retinal images were of high resolution with joint photograph expert group (JPEG) format. Red, green, and blue channels were obtained from these retinal images taken by non-mydriatic fundus camera. For RNFL loss detection, green channel is considered since red channel component does not carry any useful information. Green wave length is excellent than gray, red, and blue components of retina as shown in Fig. 2.

Dimensions of retinal images were 1500 × 1200 pixels with a field of view 45°. The damaged RNFL is due to result of decrease in RNFL bundles. Due to this, there will be lowering of reflection of incident light by the image acquisition system. Hence such a region appears darker. The visual parameter is not a feasible factor for RNFL identification. Figure 3 depicts details of another retina, showing the areas of healthy and unhealthy RNFL regions.

In this paper, testing of features was done on two sets of samples. Each square sample of size 32 × 32 was selected from the images for texture analysis using imcrop image function. In Fig. 3, the dark squares represent healthy RNF regions which are shown as dark squares and RNF loss region are shown as white squares.

1. Class A (100) samples are the healthy RNF from region of non glaucoma retina.
2. Class B (105) samples are the RNF tissue damage from patients with glaucoma.

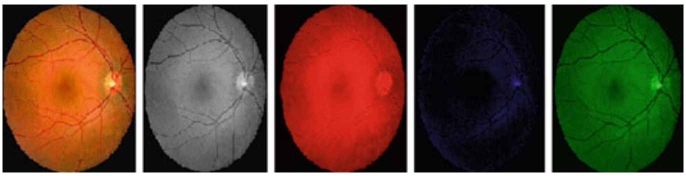


Fig. 2 Description of healthy and damaged RNFL area

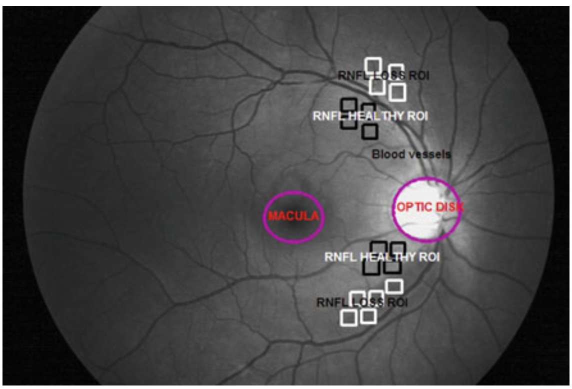


Fig. 3 Description of healthy and damaged RNFL area

The dimensions of class A and class B samples were selected in order to cover a sufficiently large area of RNFL region. The maximum dimensions of samples were controlled because blood veins, other components of retina, and pathological structure in the image may disrupt the analysis. The samples were selected in areas between macula and optic disk and surrounding area of optic disk. Pixel values were normalized to the gray level range before further processing.

Methodology

This section describes fractal theory, fractal dimension, method used to analyze texture feature of selected region, and GLCM matrix.

Fractal Theory

In 1966, mathematician of T.B.M Corporation, Mr. Mandelbrot developed a theory called noninteger or fractal theory. The word fractal defined refers to a series in which the Hausdroff–Besicovitch dimension exceeds the topological dimension.

Fractal Dimension (FD)

Fractal dimension has been used to estimate roughness in object and is helpful in modeling natural objects such as sea waves, trees, clouds, and mountains. The concept of FD is exploited to describe the texture feature of image. Fractal dimension has diverse applications in areas such as antenna design, computer simulation, and in detection of various diseases. Investigators have found several fractal dimension techniques such as box counting technique, Hausdroff dimension, power spectral fractal dimension, semi variance technique, information dimension, and perimeter fractal dimension. In this paper, we present box counting method to demonstrate the retinal image texture feature description. In next section box counting method is been described.

Box Counting Technique

The box counting technique is one of the popularly applied methods for computing fractal dimension of a binary image.

Box counting principle is defined by the ratio of logarithmic scale of number of boxes which contain ones (1 s) to the logarithmic scale of box size in a binary image as depicted in below equation

$$FD = \frac{\log N(\lambda)}{\log\left(\frac{1}{\lambda}\right)}$$

The reciprocal of box size is also recorded as $\frac{1}{\lambda}$. This procedure is iterated for all binary retinal samples extracted by several threshold values from 0.2 to 0.5 with intervals of 0.05. The fractal dimension of retinal sample is calculated as slope of line obtained by plotting graph of logarithmic of N(λ) and $\frac{1}{\lambda}$ as shown in the example below.

Assume dimension of image matrix as 4 × 4. Let the matrix be divided into 2 × 2 (ʎ = 2) subsections. Hence we obtain four submatrices of dimension 2 × 2 each. Consider N (ʎ) = 3. That is, each submatrix having a nonzero element.

If box size (S) = 2, number of boxes which contains at least 1 ones, i.e., $N(\lambda) = 3$

$$FD = \frac{\log(3)}{\log\left(\frac{1}{2}\right)} = -1.58$$

Pseudocode of BCM

For each binary retinal sample
    Divide the sample into boxes of dimension $\lambda * \lambda$
    For each box of dimension λ
        Enumerate the occupied boxes: N
        Estimate the magnitude factor $\frac{1}{\lambda}$
        End for
    End for

Gray Level Co-occurrence Matrix (GLCM)

Gray level co-occurrence matrix (GLCM) is a popular second-order statistics method to obtain texture feature from retinal images. According to GLCM method, Haralick identified 14 texture features estimated by probability matrix to obtain the characteristics of texture feature. In this paper, we describe few important features such as contrast, correlation, energy, homogeneity, entropy, etc. The contrast property is selected for implementation using MATLAB 7.10.

Contrast is a gray scale variation in the GLCM method. It estimates intensity contrast between a pixel and its neighbor over the selected region of image contrast mathematically defined in the following equation:

$$\text{GLCM contrast} = \sum_i \sum_j (x - y)^2 p(x - y)$$

In the above equation, x and y are the coordinates and p is the magnitude.

Algorithm of GLCM

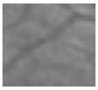
```
im1=imread('healthy.jpg');
disp(im1);
sample=imcrop(im1);
sample_resize=resize (sample [32 32]);
display(sample_resize);
disp properties glcm;
select contrast;
End.
```

Result and Discussion

MATLAB 7.10 code was written for a box counting fractal dimension & GLCM method to analyze healthy RNFL and RNFL loss. Region of interest (ROI) with different thresholds were considered ranging from 0.2 to 0.5 for BCM method to estimate fractal dimension. For damaged RNFL the FD range is 1.0772−1.840. For healthy region the FD range exceeds upper limit. Sample is analyzed for contrast property of gray level co-occurrence matrix method. The contrast value was found to be in the range of 0.0111−0.1002 for RNFL damaged region, whereas for healthy RNFL region the contrast range was above 0.100−0.3900. In the experiment, we analyzed for 100 RNF damaged samples and 105 RNF healthy samples. In Table 1, we show the result for three samples each for RNF damaged and RNF healthy. Figure 4a, b describe 1.8650 and 1.4685 FD obtained for RNFL healthy and RNFL damaged samples shown in Table 1 (Healthy 1 and Loss 1).

In Table 2, Fractal dimension and Contrast values for 32 (out of 205) samples each for healthy and unhealthy (RNFL damaged) RNFL areas are shown. We can observe in Fig. 5, contrast is ranging from 0.111 (x-axis) to 0.1222 and Fractal dimension (y-axis) is ranging from 1.079 to 1.839 for RNFL damaged area. For healthy RNFL area, contrast is ranging from 0.0972 to 0.3247 and FD is ranging from 1.844 to 1.983.

Table 1 Examples of RNFL healthy and damaged samples

	RNFL (Healthy 1)	RNFL (Healthy 2)	RNFL (Healthy 3)	RNFL (Loss 1)	RNFL (Loss 2)	RNFL (Loss 3)
Samples (RNFL healthy and damaged)						
FD	1.8650	1.8437	1.8450	1.4685	1.1965	1.0791
Con	0.2551	0.1136	0.1473	0.0667	0.0444	0.0222

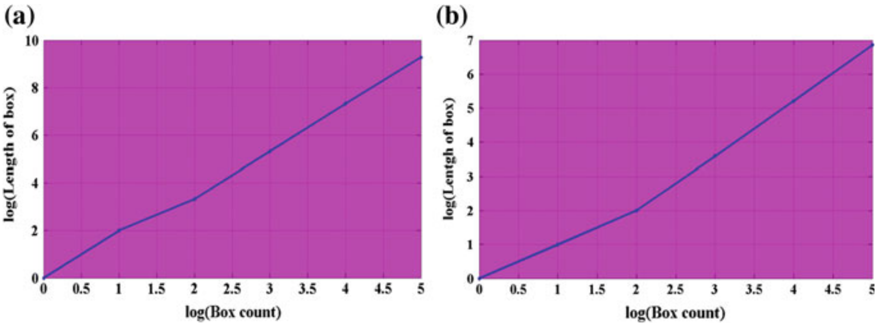


Fig. 4 Describes the estimation of fractal dimension for RNFL

Table 2 Result of 32 samples of each RNFL loss and RNFL healthy

SL. no	RNFL loss		RNFL healthy	
	Contrast	FD	Contrast	FD
1	0.0943	1.7315	0.1136	1.8437
2	0.0877	1.7777	0.1473	1.8450
3	0.0909	1.7649	0.2735	1.8444
4	0.0667	1.4685	0.2551	1.8650
5	0.0444	1.1965	0.1648	1.8744
6	0.0222	1.0791	0.2254	1.8437
7	0.0781	1.5663	0.2431	1.8437
8	0.0781	1.4728	0.2593	1.9050
9	0.0111	1.4997	0.1918	1.9150
10	0.1222	1.1773	0.2527	1.8950
11	0.0247	1.0996	0.1553	1.9350
12	0.0500	1.5233	0.1926	1.9210
13	0.1000	1.3652	0.1358	1.8999

(continued)

Table 2 (continued)

SL. no	RNFL loss		RNFL healthy	
	Contrast	FD	Contrast	FD
14	0.1074	1.7549	0.1806	1.8450
15	0.0617	1.2081	0.1616	1.8551
16	0.0972	1.6515	0.1141	1.8760
17	0.0591	1.3669	0.1233	1.8851
18	0.0751	1.7872	0.1313	1.9359
19	0.1000	1.3013	0.1477	1.8666
20	0.0606	1.3867	0.1534	1.9277
21	0.0590	1.3208	0.1600	1.8457
22	0.0598	1.2200	0.1571	1.8450
23	0.0438	1.5602	0.1583	1.9111
24	0.0300	1.2725	0.1626	1.9098
25	0.0433	1.4527	0.2692	1.8921
26	0.0614	1.3235	0.1818	1.9513
27	0.0950	1.3063	0.1174	1.9438
28	0.0646	1.3588	0.1317	1.9499
29	0.0573	1.3915	0.1761	1.9401
30	0.0751	1.3737	0.1667	1.9501
31	0.0904	1.2181	0.1639	1.8487
32	0.0598	1.3797	0.1786	1.8549

In Table 3, the values of first-order statistics such as min, max, mean, standard deviation, range, median, and mode are depicted. These values are estimated with respect to FD and contrast property of GLCM method.

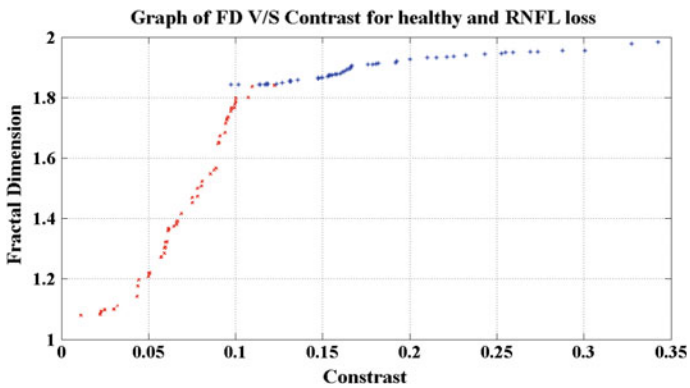


Fig. 5 Graphically shown result of RNFL healthy and unhealthy region

Table 3 Statistical data of healthy and RNFL loss texture region

SL. No	Attributes	RNFL Loss		RNFL(Healthy)	
		FD	Con	FD	Con
1	Min	1.079	0.0111	1.844	0.0972
2	Max	1.839	0.1222	1..983	0.3427
3	Mean	1.459	0.07125	1.894	0.1785
4	Median	1.434	0.672	1.887	0.1626
5	Mode	1.079	0.0598	1.844	0.0972
6	SD	0.239	0.0256	0.0404	0.0578
7	Range	0.760	0.111	0.139	0.245

Conclusion

Identifying RNFL damage through FDs and GLCM method is helpful for early glaucoma detection. GLCM method is used as second-order statistics analysis for texture property of fundus image. Positive correlation is observed for fractal dimension and GLCM property. Such experimentation can be set up in rural place also. This technique can be further enhanced by estimating RNFL and central corneal thickness (CCT). Also relationship between RNFL, CCT thickness, and image feature fractal dimension can be developed.

References

1. Odstrcilik, J., Kolar, R., Tornow, R.P., Jan, J., Budai, A., Mayer, M., Vodakova, M., Laemmer, R., Lamos, M., Kuna, Z., Gazarek, Z., Kubena, T., Cernosek, P., Ronzhina, M.: Thickness related textural properties of retinal nerve fiber layer in color fundus images. Comput. Med. Imaging Graph. **38**, 508–516 (2014)
2. Burana-Anusorn, C., Kongprawechnon, W., Kondo, T., Sintuwong, S., Tungpimolrut, K.: Image processing techniques for glaucoma detection using the cup-to-disc ratio. Thammasat Int. J. Sci. Technol. **18**(1) (2013)
3. Annadhason, A.: Methods of fractal dimension computation. In: IRACST—International Journal of Computer Science and Information Technology & Security (IJCSITS) vol. 2, No. 1 (2012). ISSN: 2249-9555
4. Mayer, M.A., Hornegger, J., Mardin, C.Y., Tornow, R.P.: Retinal nerve fiber layer segmentation on FD-OCT scans of normal subjects and glaucoma patients. Biomed. Opt. Express **1**(5), 1358 (2010)
5. Bock, Rüdiger, Meier, Jörg, Nyúl, László G., Hornegger, Joachim, Michelson, Georg: Glaucoma risk index: automated glaucoma detection from color fundus images. Med. Image Anal. **14**, 471–481 (2010)
6. Huang, X.-R., Knighton, R.W., Shestopalov, V.: Quantifying retinal nerve fiber layer thickness in whole-mounted retina. Exp. Eye Res. **83,** 1096e−1101 (2006)
7. Park, J., Kemp, N.J., Zaatari, H.N., Milner, T.E., Rylander, H. G.: Analysis of phase retardation in the primate retinal nerve fiber layer by polarization sensitive optical coherence tomography. In: Proceedings of the *25** Annual International Conference of the IEEE EMBS, Cancun, Mexico, 17−21 Sept 2003

8. Lu, S., Cheung, C.Y., Liu, J., Lim, J.H., Leung, C.K., Wong, T.Y.: Automated layer segmentation of optical coherence tomography images. IEEE Trans. Biomed. Eng. **57**(10) (2010)
9. Zhu, H., Crabb, D.P., Schlottmann, P.G., Wollstein, G., Garway-Heath, D.F.: Aligning scan acquisition circles in optical coherence tomography images of the retinal nerve fibre layer. IEEE Trans. Med. Imaging **30**(6) (2011)
10. Acharya, U.R., Dua, S., Du, X., Vinitha Sree, S., Chua, C.K.: Automated diagnosis of glaucoma using texture and higher order spectra features. IEEE Trans. Inf. Technol. Biomed. **15**(3) (2011)
11. Gazarek, J., Jan, J., Kolar, R., Odstrcilik, J.: Retinal nerve fibre layer detection in fundus camera images compared to results from optical coherence tomography. In: International Conference on Image Information Processing (ICIIP 2011) (2011)
12. Lamani, D., Manjunath, T.C., Ramegowda: Cup-disk segmentation and fractal dimension to detect glaucomatous eyes. In: National Conference on Current Trends in Research and Technology (CRT-13), Sponsored by IET (The Institute of Engineering & Technology, UK), SDMIT, Ujire, South Kanara, Karnataka, India, 27−28 Sep 2013
13. Lamani, D., Manjunath, T.C., Ramegowda: Fractal dimension with object rotation: a case study with glaucoma eye. In: 5th IEEE International Conference on Signal and Image Processing (ICSIP-2014), BNMIT, Bangalore, Karnataka, India, 978-0-7695-5100-5/13 $31.00 © 2013 IEEE DOI 10.1109/ICSIP.2014.22, ISBN: 978-0-7695-5100-5, Paper No. ICSIP-31, Session-Medical Image Processing, pp. 111−116, 8−10 Jan 2014
14. Lamani, D., Manjunath, T.C.: Automatic detection of diabetes retinopathy through image feature power spectral fractal dimension. In: 8th Elsevier International Conference on Image and Signal Processing (ICISP-2014), UVCE, Bangalore, Karnataka, India, Paper ID : ICISP-357, Reference No.: 357I-S, 25−26 July 2014
15. Kersey, T., Clement, C.I., Bloom, P., Cordeiro, M.F.: New trends in glaucoma risk, diagnosis & management. Indian J Med Res **137**, 659−668 (2013)
16. Kolar, R., Tornow, R.P., Jan, Laemmer, R., Odstrcilik, J., Mayer, M.A.: Analysis of visual appearance of retinal nerve fibers in high resolution fundus images: a study on normal subjects. Comput. Math. Methods Med. **2013**, Article ID 134543, 1−10 (2013)
17. Kolar, Radim, Jan, Jiri: Detection of glaucomatous eye via color fundus images using fractal dimensions. Radio Eng. **17**(3), 109–114 (2008)
18. Kolar, R., Vacha, P.: Texture analysis of the retinal nerve fiber layer in fundus images via Markov random fields. In: IFMBE Proceedings 25/XI, pp. 247–250 (2009)
19. Cheung, C.Y.L., Leung, C.K.: A practical guide for interpretation of optical coherence tomography retinal nerve fiber layer measurement. J. Current Glaucoma Pract. **1**(3), 9–13 (2009)
20. Lamani, D., Manjunath, T.C., Kulkarni, U.P.: Automated detection of neovascular glaucoma through fractal dimension method. Int. J. Comput. Sci. Inf. Technol. **5**(4), 5252−5257 (2014). ISSN: 0975-9646