Neuroretinal rim Quantification in Fundus Images to Detect Glaucoma

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Summary
Early detection of structural damage to the optic nerve head is critical in diagnosis of glaucoma, because such glaucomatous damage precedes clinically identifiable visual loss. Glaucoma is the second leading ocular disease and early detection of glaucoma can prevent progression of the disease and consequent loss of vision. Segmentation of optic disc cup and neuroretinal rim can provide important parameters for detecting and tracking this disease. This paper proposes an approach for the automatic localization and exact boundary detection of optic disc using the component analysis method and region of interest (ROI) based segmentation. Connected component analysis method is used to detect optic cup. The method is compared with manual thresholding approach and later the active contour is used to plot the boundary accurately. The proposed method can be used to automatically segment the neuroretinal rim area using mask to filter ISNT quadrants. Neuroretinal rim area is calculated in each of the quadrants separately to suspect glaucoma. This method is tested on image data sets from Aravind Eye Hospital, Madurai and compared with the Ophthalmologists data. Features of glaucomatous disc damage like CDR, asymmetry between left and right eye, neuro retinal rim area, ISNT, was evaluated to suspect glaucoma.

Key words:
Glaucoma, fundus, Region of Interest (ROI), Cup to Disc Ratio (CDR), ISNT(inferior,superior,nasal,temporal quadrants).

1. Introduction

Glaucoma is defined as 'multi factorial optic neuropathy' which is a potentially blinding disease which affects 66.8 million people worldwide. It is the second leading cause of blindness. Risk assessment of the disease goes a long way in diagnosis and management of the disease. Although the raised intra ocular pressure (IOP) is a significant risk factor for developing glaucoma, there is no set threshold for IOP that causes glaucoma. This can result in decreased peripheral vision and eventually leads to blindness. Early glaucomatous damage can be difficult to detect, requiring careful observation of the optic nerve and RNFL. The detection of glaucoma through Optical Coherence Tomography (OCT) and Heidelberg Retinal Tomography (HRT) are very expensive [1, 2] compared to digital fundus images. With the help of image processing, the features of the fundus images such as optic disc and cup could be localized to suspect the glaucoma [3, 4, 5]. The detection of OD position and automated feature extraction is a pre-requisite for the computation of some important diagnostic indexes like glaucoma [9]. The optic disc and cup were located by identifying the area with the highest variation in intensity of adjacent pixels [6]. This paper presents the automatic detection of optic disc by region of interest based segmentation and component labeling. As the shape of the optic disc is important to diagnose eye diseases, the exact boundary detection of the optic disc is investigated [13]. "Active Contour" was applied to detect the exact contour of optic disc[10]. The major advantage of this method is their ability to bridge the discontinuities in the image features being located. Then the number of white pixels was calculated to find the area of disc and cup from the result obtained by the above mentioned methods. The estimation of boundary was achieved by active contour. With the help of detected area of disc and cup the CDR can be evaluated automatically[8].Neuroretinal rim area can be measured by configuration to suspect glaucoma[7] The ISNT rule states that in a healthy optic disc, the widest rim tissue is found inferiorly, then superiorly, nasally, with the temporal rim being the thinnest[14]. Finally a comparison of all factors is done to detect the effect of glaucoma. Features such as cup to disc (c/d) ratio, the ratio of blood vessels area in inferior-superior side to area of blood vessel in the nasal-temporal side are extracted and validated by classifying the normal and glaucoma images[11].

2. METHODOLOGY

A. Extraction of Optic Disc

1. Manual Threshold Analysis:
The formulation of the manual threshold for extracting the optic disc includes the removal of the blood vessels in the retinal images. The morphological operation such as the dilation, erosion, is performed on the input image(fig 1). The morphological functions are applied to do pre-processing [6].

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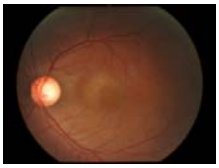


FIG 1: Input image

Dilation is the operation that combines two sets using vector addition of set elements.
Let A and B are subsets in 2-D space. A: image undergoing analysis, B: Structuring element,

$$A \oplus B = \{c \in Z^2 \mid c = a + b \text{ for some } a \in A, b \in B\} \quad (1)$$

Dilation causes objects to grow in size by adding pixels to the boundaries of the object in the input image.Erosion is the morphological dual to dilation. It combines two sets using the vector subtraction of set elements.

$$A \ominus B = \{x \in Z^2 \mid \text{for every } b \in B, \text{exist an } a \in A \text{ s.t. } x = a - b\}$$
$$= \{x \in Z^2 \mid x + b \in A \text{ for every } b \in B\} \quad (2)$$

Erosion is done to contrast the boundary of the object. The result of this operation has smooth image without any blood vessels. Individual pixels in a grayscale image are marked as 'object' pixels if their value is greater than some threshold value (assuming an object to be brighter than the background) and as 'background' pixels otherwise. Typically, an object pixel is given a value of '1' while a background pixel is given a value of '0'. The minimum threshold value of the disc is set in order to extract the optic disc boundary. The boundary is estimated by plotting the boundary over the input image.

2. Color Component Analysis:
In this method we explore the component analysis method RGB components of the image are analyzed, it was found that the optic disc was more easily discriminated in RED image [11]. In order to measure disc more accurately, the blood vessels in the image had to be removed. This is achieved by performing the closing and opening operation. Opening is similar erosion and it tends to remove some of the foreground pixels from the edge of region of foreground pixels [6]. First CLOSE operation is done followed by the OPEN [12]. The boundary of the optic disc is detected by converting the opening image into the binary image in which white pixels closely approximate the edge of the optic disc. This method accurately determines the boundary of the optic disc only when the image has the contrast disc.

3.ROI based segmentation:
In this method the optic disc is extracted by finding the region of interest based on colors. In order to calculate the ROI , in the original image the mathematical morphology like dilation, erosion is done to smoothen the image. After performing the morphological functions the small holes gets filled and object boundary is smoothen. The ROI for the input image is then examined; the result of this step gives the binary image of the optic disc. To localize the boundary exactly the component labeling is used. In this image areas are labeled by using the neighborhood connecting pixels. All the connected pixels with the same input value are assigned the same identification label. Figure (2) shows the component labeling algorithm.

(a) (b)

FIG.2. Result from the component labeling
(a)Before labeling (b) After labeling.

B. Extraction of Optic Cup
Component Analysis Method:
The segmentation of optic cup is considerably more challenging than the optic disc due to high density of vascular architecture traversing the cup boundary[12]. The disc and cup could not be easily distinguished as the border between the two was unclear. The component analysis method will localize the optic cup efficiently, even though the image is low contrast. In this paper, we extract the green component from the original fundus image in order to detect the cup.The morphological operation like closing and opening are performed to get the area of cup more accurately [6]. The close operation would fill the gap of the cup and also smoothen its boundary. The open operation would remove any small stray bright spots that are present in the image [12]. The component analysis method detects the area of the cup more accurately than the manual threshold analysis. Later the result of the morphological image is converted to binary image. The exact optic cup was obtained from the binary image. By calculating the number of white pixels in the binary image obtained, the area of cup was measured.

3. EXPERIMENTAL RESULTS

The first row represents the input image and the second row shows the results of manual threshold analysis. The third row represents simulation results of component

analysis for cup and disc. The last row gives the result obtained from ROI based segmentation method for disc and component analysis for the cup. In third and last row the cup was same, because in both component analysis method was used.

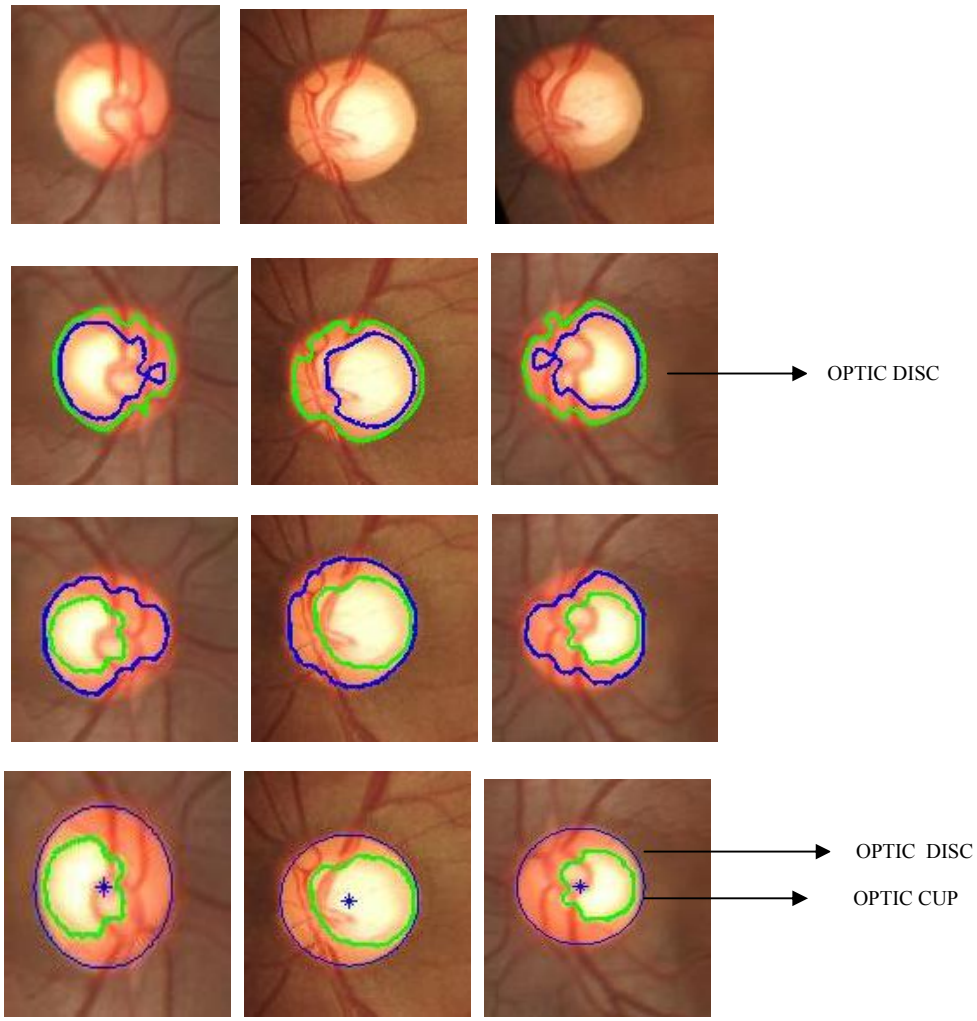
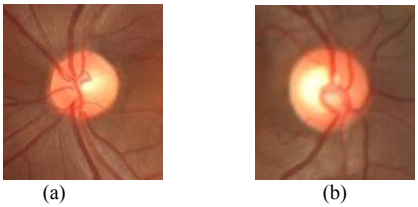


FIG 3. First row: Test images ;
Second row: Result from manual threshold
Third row: Result from component analysis
Fourth row: result from ROI method.

4. DETERMINATION OF FACTORS TO SUSPECT GLAUCOMA

1. CDR calculation

Cup to Disc ratio greater than 0.3:1 is the most often reported sign of disc damage. Increase in the cup-disc ratio or the enlargement of the cup over a period of time is diagnostic of glaucomatous disc damage.First and foremost feature is the cup to disc ratio, which specifies the change in the cup area. Due to glaucoma the cup area will increase slowly by intra ocular pressure (IOP) and results in dramatic visual loss. In this paper increase in cup area is analyzed by examining the CDR value. The CDR was calculated by taking the ratio between the area of optic cup and disc. CDR > 0.3 indicates the suspection of glaucoma and CDR $\leq$ 0.3, is considered as normal image(fig 4).



(a) (b)

FIG 4. suspection of glaucoma

(a) CDR ≤ .3 (b) CDR > 0.3

2. Neuro retinal rim Evaluation

Loss of axons in Glaucoma is reflected as abnormalities of the neuroretinal rim. Identification of the neuroretinal rim width in all sectors of the optic disc is of fundamental importance for detection of diffuse and localized rim loss in glaucoma[14]. The rim width is calculated using ISNT rule.

ISNT calculation:

Rim area is measured in the ISNT quadrants. Usually the rim area thickness must be more in the superior and inferior region when compared to the temporal and nasal region[15].To obtain the thickness in all the four quadrants, a binary image of the neuro retinal rim is taken and then cropped as in fig (5). A mask of the cropped image size is used to filter one quadrant[11]. Then the mask is rotated 90º to obtain the other quadrant area. Fig 6 shows the mask used for identifying rim area in the ISNT side of optic disc. Fig. 7 shows the rim area in the vicinity of optic disc.

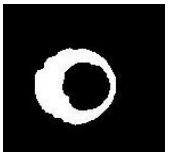
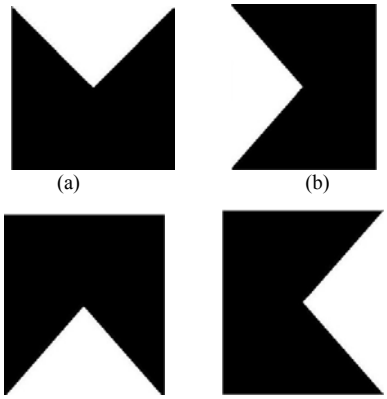


FIG 5. Neuro retinal rim area.

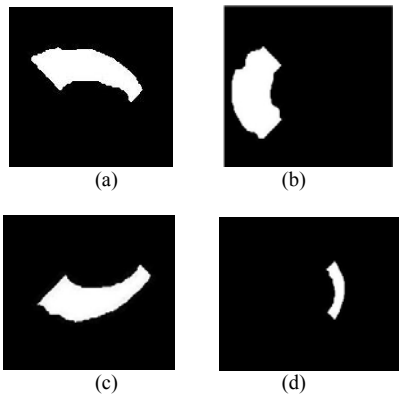


(a) (b)

(c) (d)

FIG.6 Mask used for detecting the Rim area in (a) superior side; (b) temporal side; (c) inferior side; (d) nasal side of the optic disc

This neuroretinal rim configuration gives rise to a cup shape that is either round or horizontally oval. Neuro retinal rim area is calculated by subtracting the area of the optic cup from area of optic disc Normally the rim is the widest in the inferior temporal sector followed by the superior temporal sector, the nasal and the temporal horizontal sector. In this paper the neuro retinal rim area is detected to identify the thickness.



(a) (b)

(c) (d)

FIG.7 Rim area in (a) superior side; (b) temporal side; (c) inferior side; (d)nasal side of the optic disc

Image	cdr.roi	cdr.clinical	Superior	Inferior	Nasal	Temporal	ISNT
G1	0.3174	0.38	3.23E+03	2459	2.24E+03	1.38E+03	2459 (I)
G2	0.3251	0.35	5.88E+03	6.73E+03	4.63E+03	8.23E+03	4673.8 (N)
G3	0.2216	0.25	4556	5.80E+03	2106	8591	4556 (S)
G4	0.4956	0.5	1.36E+03	1.13E+03	1.08E+03	1591	1125.1 (I)
G5	0.3012	0.25	7.09E+03	7.58E+03	5.02E+03	3.96E+03	7091.5 (S)
G6	0.3712	0.35	4.61E+03	5.48E+03	2.31E+03	9.97E+03	4614.5 (S)
G7	0.3543	0.35	3.67E+03	5.05E+03	2.41E+03	5.99E+03	3678.2 (S)
G8	0.3627	0.4	6.67E+03	7.22E+03	5.08E+03	3.59E+03	6678.1 (S)
G9	0.2089	0.2	5.11E+03	9.42E+03	5.16E+03	5.79E+03	5514.6 (S)
G10	0.506	0.55	5.05E+03	5.06E+03	1.92E+03	7218	5056 (S)
G11	0.6104	0.7	1.20E+03	2.23E+03	1.40E+03	622.75	1203.6 (S)
G12	0.4877	0.45	4.54E+03	5819	6.80E+03	2.75E+03	4543.9 (S)
G13	0.26578	0.25	4976	6.76E+03	2626	9.43E+03	4976 (S)
G14	0.3638	0.35	4039	5.20E+03	3816	9.10E+03	4039 (S)
G15	0.2073	0.2	6.31E+03	5.29E+03	2.76E+03	6867	2768 (N)

Table 1: Comparision of CDR and ISNT ratio to suspect glaucoma

Image	CDR	NRRA	ISNT	Disc-Diameter	NRRA-Disc Diameter	Classification
G1	0.3174	0.38	9.29E+03	70	5.224	advance
G2	0.3251	0.35	8.732	79	3.425	advance
G3	0.2216	0.25	2.10E+04	156	0.1873	normal
G4	0.4956	0.5	5.15E+03	86	2.358	suspect
G5	0.3012	0.25	2.36E+04	138	5.29E+00	advance
G6	0.3712	0.35	2.24E+04	162	5.43E+00	advance
G7	0.3543	0.35	1.71E+04	122	5.516	advance
G8	0.3627	0.4	2.25E+04	108	4.213	advance
G9	0.2089	0.2	2.54E+04	134	3.678	.suspect
G10	0.506	0.55	1.92E+04	124	5.09E+00	advance
G11	0.6104	0.7	5.44E+03	90	2.38E+00	suspect
G12	0.4877	0.45	1.99E+04	124	5.26	advance
G13	0.26578	0.25	23757	152	5.78E+00	advance
G14	0.3638	0.35	2.21E+04	134	5.91E+00	advance
G15	0.2073	0.2	2.12E+04	188	1.99E-01	normal

Table 2: Comparison of various features to suspect glaucoma

In the normal image cdr is ≤ 0.3.Large optic discs have large cups and often elevated C/D ratios. They can be incorrectly labeled as glaucomatous. Similarly small discs with a small C/D ratio may actually be pathologic and be erroneously classified as normal. So inferior & superior rim width thickness is to be considered which is maximum and nrri/disc diameter should be<0.2mm in the normal images and for glaucoma suspect inferior & superior rim width thickness will be minimum nrri/disc diameter should be>0.2mm.

IMAGES	Superior Area (L)	Inferior area (L)	superior Area (R)	Inferior area(R)	Disc area (L)	Disc area(R)	Rim to Disc ratio(L)	Rim to Disc ratio(R)
I1	710.625	606.125	470.87	237.378	3.81E+03	4258	0.1866	0.11058
I2	5.78E+02	669.12	371	293.125	3.75E+03	4.33E+03	0.15433	0.0857
I3	259.25	469.75	632.37	492.25	3.46E+03	4.07E+03	0.07483	0.155511

Table 3: Rim to Disc ratio for different images for left and right eye

By calculating this ratio the extent of disc damage can be identified. The stage of disc Damage in the proposed method is for the medium sized disc and it resembles disc damage likelihood scale obtained from the ophthalmologist.

IMAGES	Rim to Disc ratio(L)	Rim to Disc ratio(R)	Stage of Disc Damage (Left)	Stage of Disc Damage (Right)
I1	0.1866	0.11058	1	1
I2	0.15433	0.0857	1	2
I3	0.07483	0.155511	2	1

5. POSTULATION

This work proposes the recognition of Glaucoma in advance. It is important to diagnose Glaucoma as early as possible to minimize the damage to optic nerve head as examination of the optic nerve is a crucial part of an evaluation for glaucoma. The detection of Glaucoma by Optical Coherence Tomography (OCT) and Heidelberg Retinal Tomography (HRT) used to differentiate between the glaucoma and non-glaucoma eye is very expensive. But in the proposed paper the fundus photograph which is used is less expensive and provides a reliable approach to incorporate the evaluation of disc size and rim width in clinical grading of the disc

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6. CONCLUSION

The algorithms for the identification of Glaucoma by estimating CDR were developed in this paper. ROI based segmentation is proposed to localize optic disk, which is estimated by using contour method exactly, when compared with other methods even though the image is in low contrast. The optic cup was segmented using the component analysis and the threshold methods separately. The performance of various methods was evaluated using the proximity of the calculated CDR to the clinical CDR. It was found that ROI, combined with the component Analysis method provides the better estimation of CDR.C/D ratio does not take into consideration the diameter of the disc and hence it is prone to give false positive and false negative impressions. The proposed work focuses on how much the neuroretinal rim tissue is present. By categorizing the discs as small, medium or large, the expectation of rim thickness can be adjusted. This reduces the misclassification based on the disc size. It also takes into consideration the focal loss of rim tissue. Neuroretinal rim area evaluation may increase the value in clinic practice for automatic screening of early diagnosis of Glaucoma. The results presented in this paper indicate that the features are clinically significant in the detection of glaucoma.

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