A simple approach to Cup-to-Disk Ratio determination for Glaucoma Screening

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Abstract: This paper proposes a simple and novel method to evaluate the Cup-to-Disc Ratio (CDR) of a color retinal fundus image to screen it for Glaucoma. Since Glaucoma is one of the major pathologies that lead to blindness, it is mandatory to detect it at early stages. The CDR value is the first and foremost feature taken up to check whether the subject is at risk for Glaucoma or not. The technique proposed applies simple morphological techniques to extract out CDR value and ultimately classify the subjects as suspected for Glaucoma or normal.

Keywords: Glaucoma, Optic Disk, Optic Cup, Cup-To-Disc Ratio (CDR), Intraocular Pressure (IOP), Optic Nerve Head (ONH), Retinal Nerve Fiber Layer (RNFL).

Introduction

Glaucoma has been the second most common reason of blindness today. At early stages it is hard to detect whether the subject is going to develop Glaucoma or not and various features are analyzed to conform the same. Glaucoma basically refers to a group of eye diseases that result due to the damaged Optic nerve. This damage is mostly associated with the elevated eye pressure, as shown in Figureure 1, which is increased by the blockage of the eye canal through which clear fluid within the eye known as the aqueous humor flows. Firstly, the eye pressure is measured using a tonometer [1, 2]. If this pressure, also known as Inter Ocular Pressure (IOP), exceeds the normal range, i.e. 10-21 mm of Hg, then the subject is considered suspicious. Also, not all the subjects with elevated eye pressure may have Glaucoma. The increased IOP refers to the presence of a pathology which is further confirmed by analyzing various features of the fundus retinal image using the image processing techniques. Due to the increase in the IOP, the area and size of the Optic Cup increases, as shown in Figureure 2, this affects the Cup-to-Disk Ratio and acts as the contrasting feature in analyzing the subject for the screening of Glaucoma. For a normal eye, the CDR value ranges from 0.3 to 0.5. If this ratio exceeds 0.5, the subject is considered suspicious for Glaucoma.

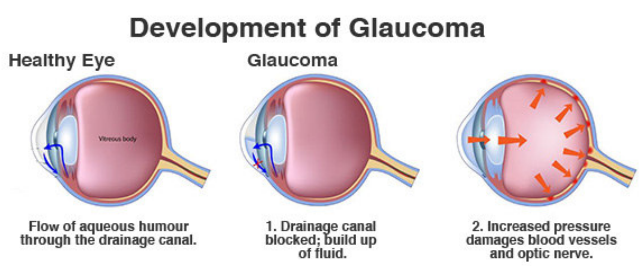

Figure 1: Development of Glaucoma [3]

The Cup-to-Disk Ratio is calculated by mathematically dividing the value of Cup diameter by the Disk diameter (taken vertically),

$$\text{Cup-to-Disk Ratio} = (\text{Cup diameter}) / (\text{Disk diameter})$$

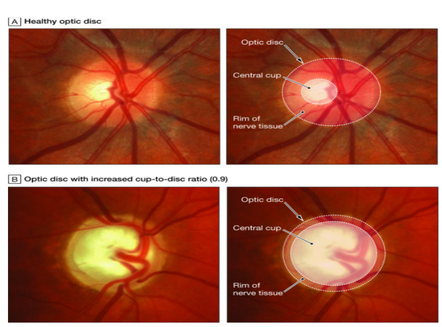

Figure 2: (a) Healthy Optic eye, (b) Eye with increased Cup-to-Disk Ratio [4]

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There have been so many techniques that have been proposed and used to detect Glaucoma by extracting out the Optic Cup and Disk and then calculating the CDR value from it [5].The image database on which the proposed methodology has been applied consists of a total of 12 retinal fundus images. These images are taken from the local physician using a digital ophthalmoscope. These are acquired at an angle of 45^0 from the posterior pole.

Proposed Methodology

For the screening of Glaucoma, the most significant feature is the Cup-to-disc Ratio (CDR). It signals whether the subject is suspicious for Glaucoma or not. For the calculation and evaluation of the CDR value, firstly the diameter of the Optic disc and the Cup are required. The normal CDR values range from 0.3 to 0.5 and values greater than 0.5 are considered suspicious. The basic method of the proposed methodology is shown in Figureure 3.

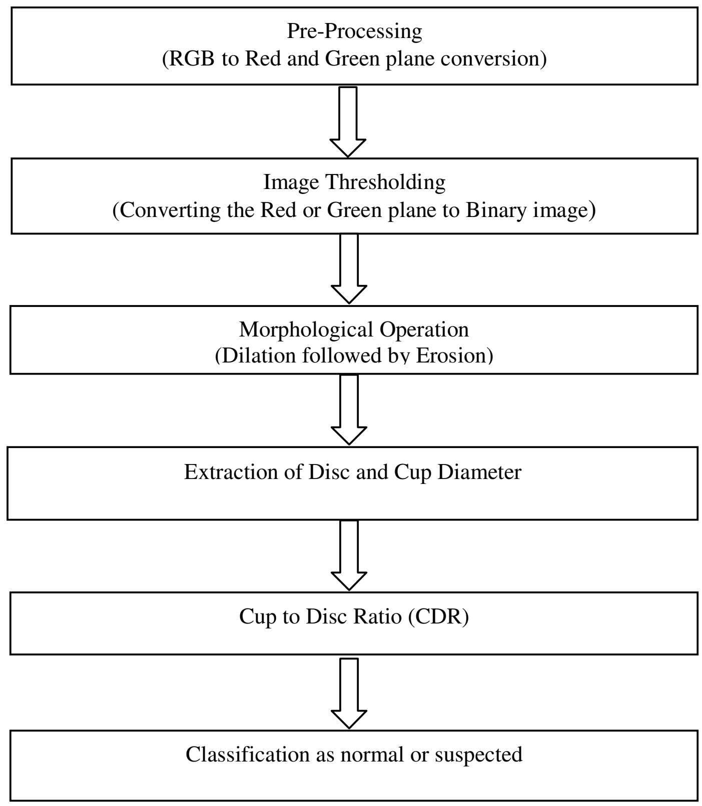


Figure 3: Method for extraction of Cup-to-disc Ratio

A. Image Preprocessing

After the analysis of a number of retinal images it was concluded that the optic disc has a better contrast in the Red plane and the optic Cup has a better contrast in the Green plane. Image preprocessing involves the extraction of the Red plane (in case of the optic disc) and the Green plane (in case of optic cup) from the original color retinal fundus image for the extraction of the Disc and the Cup.

B. Extraction of Optic Disc and Optic Cup

The evaluation of CDR involves the extraction of the Disc and the Cup, to detect the same the Red and Green plane extracted out are then converted into the binary image by thresholding with a specific level or value of threshold for Disc as well as the Cup.
For the extraction of the Optic Disc, the Red plane is first converted to the binary image as mentioned earlier. The binary image so obtained has gaps and uneven boundaries in it. As a remedy for these gaps and unsymmetrical boundaries, morphological operations are applied to this binary image. The binary image is applied with the 'CLOSE' operation by using the structuring element 'DISK'. This operation basically involves dilation followed by erosion.

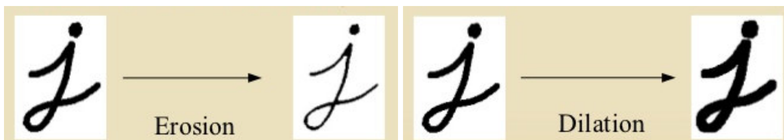
Dilation is one of the core morphological operations that usually use a structuring element for scrutinizing and expanding the shapes in the input image, where a structuring element is an element or a mask used to probe a given image to check as in on how this shape fits or misses the similar shapes in the image. The mathematical formula for dilation is written as:

$$A \oplus B = \{z | (\hat{B})_z \cap A \neq \Phi\}$$

where$A$ is the input image and B being the structuring element.
Erosion on the other hand erodes away the boundaries of foreground region i.e. removes structures of certain shape and leads to shrinking of the objects. Erosion can be mathematically expressed as:

$$A \Theta B = \{z | (B)_z \subseteq A\}$$

A is again the input image and B the structuring element.
The concept of erosion and dilation can be understood by the Figure: 4 (a) and (b).



(a) (b)

Figure 4: Effect of (a) Erosion, (b) Dilation [6]

The closing and opening can be expressed as,

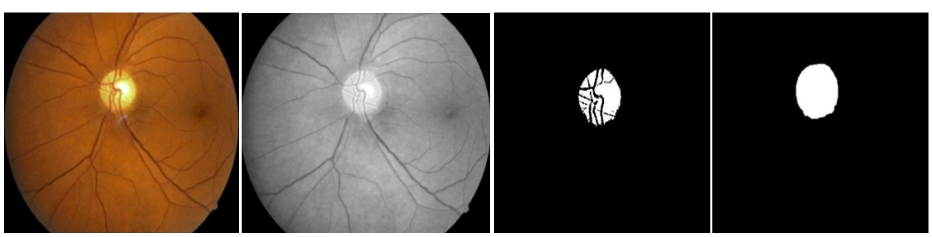
Closing,

$\bullet$ Θ

Opening,

$$A \circ B = (A \Theta B) \oplus B$$

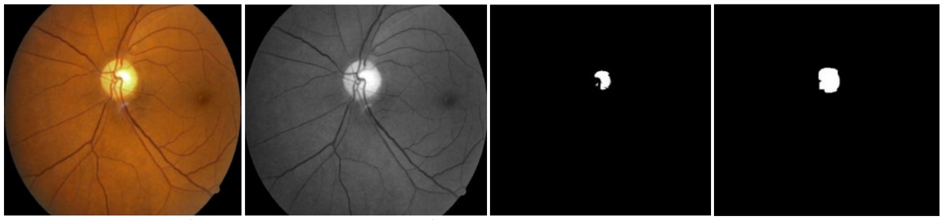
The CLOSE operation, as mentioned earlier, is dilation followed by erosion. Due to dilation the diameter of the required cup increases first, but as it is followed by erosion it compensates for the increased dimension (as the structuring element used is same and of same dimension as well). This closing operation fills in all the gaps in the binary image that are held in the Optic Disc and alsosmoothes the contour of the extracted disc.
Also sometimes the binary image obtained, along with the Disc, contains unwanted areas. To remove these small unwanted parts 'Area Opening' is done which provides us with a final image that only contains the Optic Disc and no unwanted areas. Since the optic disk detected is in the form of an ellipse, so the major axis of this ellipse denotes the diameter of the Disc (taken vertically). Figure 5 shows the output images obtained after applying different steps of the methodology.



(a)(b) (c) (d)

Figure 5: (a) Original color fundus image, (b) Red plane, (c) Binary Optic Disc, (d) Morphologically Operated Disc

The extraction of the cup first involves the conversion of the Green plane of the original retinal fundus image to a binary image using thresholding using a fixed threshold. This binary image so obtained contains the optic cup but with irregular gaps. These gaps are then filled by using the morphological operation 'CLOSING' using the 'DISK' structuring element but with a different radius from the one used for Disc detection. The Cup is also extracted as an ellipse whose major axis is taken as its diameter as shown in Figure 6.



(a)(b) (c) (d)

Figure 6: (a) Original color fundus image, (b) Green plane, (c) Binary Optic Cup, (d) Morphologically Operated Cup

The Cup-to-Disc ratio is denoted as the ratio of the diameter of the cup to that of the disc. The values obtained above are used to formulate the CDRvalues which are further used for the classification of the images or subjects as normal or suspicious for Glaucoma.

C. Classification

The subjects are classified as normal or suspected for Glaucoma on the basis of the CDR threshold values. The images with CDR values ranging from 0.3 to 0.5 are classified as the normal ones and those with values greater than 0.5 are screened for Glaucoma or are considered at risk for Glaucoma.

Results

The above mentioned methodology screens the sample images for Glaucoma i.e. whether the subject is normal or suspected. The methodology has been applied on a total of 12 images. The true value of CDRis provided by the physician and is taken as gold standard. The table given below compares the CDR values of 12 of the total samples obtained from the proposed methodology with the true values.

Table 1: Comparison of True and Measured CDR Values

Sample no.	Disk		Cup		CDR(Measured) = Cup(measured)/ Disk(measured)	CDR(True) = Cup(true)/ Disk(true)	Measured	True
	Measured	True	Measured	True				
1	98	96	40	41	0.40	0.40	Normal	Normal
2	120	123	68	68	0.56	0.55	Glaucomatous	Glaucomatous
3	114	120	55	52	0.50	0.43	Normal	Normal
4	121	119	73	64	0.60	0.54	Glaucomatous	Glaucomatous
5	105	126	73	59	0.60	0.46	Glaucomatous	Normal
6	100	104	-	57	-	0.54	-	Glaucomatous
7	92	97	-	26	-	0.30	-	Normal
8	120	112	40	45	0.34	0.40	Normal	Normal
9	106	104	50	38	0.47	0.36	Normal	Normal
10	79	108	69	68	0.80	0.63	Glaucomatous	Glaucomatous
11	134	139	98	80	0.73	0.60	Glaucomatous	Glaucomatous
12	134	141	97	88	0.68	0.62	Glaucomatous	Glaucomatous

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The Figure 6 shows the comparison of true and measured CDR values for Glaucomatous and Healthy samples respectively.

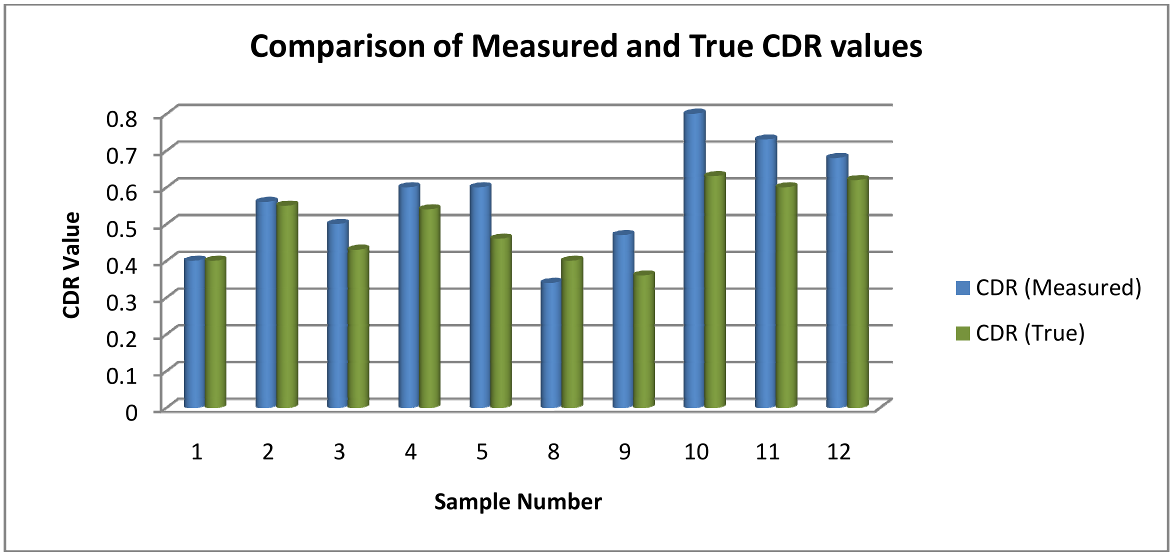

Figure 6: Comparison of true and measured CDR values

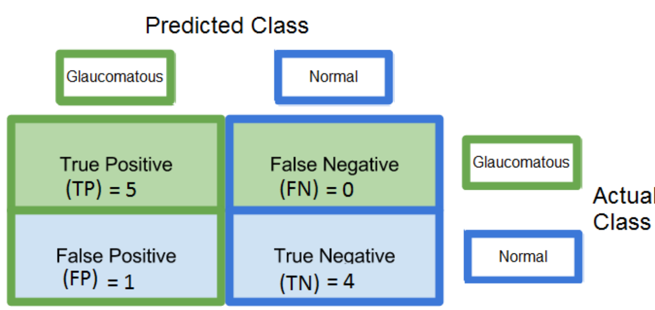

Figure 7: Confusion Matrix

TP (true positive) here depicts the number of samples correctly classified as Glaucomatous. TN (true negative) signifies the number of samples correctly classified as normal samples. FN (false negative) and FP (false positive) signifies the number of samples incorrectly classified as normal and Glaucomatous respectively.
The Accuracy, Sensitivity and Specificity of the proposed algorithm can be calculated as:

- Accuracy= (TP+TN)/ (P+N) = (5+4)/ (5+5) = 0.9 or 90%,
- Sensitivity = TP/ (TP+FN)= 5/ (5+0) = 1 or 100%,
- Specificity = TN/ (TN+FP) = 4/ (4+1) = 0.8 or 80%

To further refine our methodology and to validate it, it is proposed to extend this study for 50 images.

Conclusions

A simple methodology is proposed for the screening of Glaucoma. The proposed methodology uses the Morphological operations for the extraction of the Optic Disc and the Cup and ultimately the Cup-to-Disc Ratio. The CDR value for the normal subjects came out to be equal to or less than 0.5 and for the suspicious subjects came greater than 0.5. Of the 12 fundus images under study, our algorithm is able to detect CDR in 10 images. Further, in the detected 10 images 9 are detected correctly.

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