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Glaucoma Detection in Color Fundus Images Using Cup to Disc Ratio

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ABSTRACT

GLAUCOMA is a group of diseases that can damage the eye's optic nerve and result in vision loss and permanent blindness. Glaucoma is a disease characterized by elevated intraocular pressure (IOP). This increased IOP leads to damage of optic nerve axons at the back of the eye, with eventual deterioration of vision. CDR is a key indicator for the detection of glaucoma. The ratio of the size of the optic cup to the optic disc, also known as the cup-to-disc ratio (CDR), is one of the important clinical indicators of glaucoma, and is currently determined manually by trained ophthalmologists, limiting its potential in mass screening for early detection. In this paper, we propose a method to calculate the CDR automatically. Preprocessing methods such as anisotropic filtering have been performed. Automatic disc extraction is done using 3 techniques 1) Edge detection method, 2) Optimal thresholding method, and 3) Manual threshold analysis. Threshold level-set method is used for the detection of cup. The methods have been tested on the images in the publicly available DRIVE database.

KEYWORDS : *Color Fundus Images,Glaucoma,Optic Cup,Optic Disc,Cup-toDisc Ratio(CDR).*

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I. INTRODUCTION

The Glaucoma is a condition that causes damage to your eye's optic nerve and gets worse over time. It's often associated with a buildup of pressure inside the eye. The increased pressure, called intraocular pressure (IOP), can damage the optic nerve, which transmits images to the brain. Glaucoma will cause permanent loss of vision if damage to the optic nerve due to high eye pressure continues. Without treatment, glaucoma can cause total permanent blindness within a few years. Glaucoma is one of the common cause of blindness and about 79 million people in the world are likely to be affected by glaucoma by the year 2020 [1]. It is a complicated disease in which damage to the optic nerve leads to progressive, irreversible vision loss. Glaucoma has no early symptoms or pain hence it is required to see the doctor regularly as early detection and treatment is essential to prevent damage to the vision [2].Glaucoma has been called the "silent thief of sight" because the loss of vision often occurs gradually over a long period of time, and symptoms only occur when the disease is quite advanced. Once lost, vision cannot normally be recovered, so treatment is usually aimed at preventing further loss. One of the glaucomatous changes observed in the retinal fundus images of affected individuals is enlargement of depression, called cupping, of optic disc and/or local rim thinning. An ophthalmologist will diagnose Glaucoma by measuring the CDR (Cup to Disc Ratio) which is the ratio of the vertical height of the optic cup and optic disc. This work is focused on the determination of the disc regions. The cup-to-disc ratio (CDR) expresses the proportion of the disc occupied by the cup and it is widely accepted index for the assessment of glaucoma [4]. For normal eye it is found to be 0.3 to 0.5 [3]. As the neuro-retinal degeneration occurs the ratio increases and at the CDR value of 0.8 indicates complete loss of vision. Several studies are reported in the literature for the detection of optic disc and the classification of glaucoma disease. Walter and Klein [5] have proposed a method based on the morphological operation; applying the watershed transformation to the gradient image. The method proposed by Li and Chutatape [6] is an active shape model, which consists of building a model with training cases and iteratively matching the landmark points on the disc edges and main vessels inside the disc. M. Kass, A. Witkin, D. Terzopoulos [7] proposed a method investigated for the determination of optic disc regions is based on the active contour modeling. In this method, expected disc borders has been searched in radial directions from the center of an ROI. In another approach by

Gopal Datt Joshi [8], region based active contour method has been used which avoided intensity variations due to vessels. However the cup deformation shall not be uniform due to variations in vessels.

In this study, we propose a method namely anisotropic diffusion filtering as a pre-processing step. The bright speckles distributed over the images are reduced without losing important information about disc and cup boundaries by using anisotropic diffusion filtering [10]. Three methods are used to automatically extract the optic disc, 1) Edge detection method [11],[12], 2) Optimal thresholding method[13] and 3)Manual threshold analysis[14]. Cup is extracted using Threshold level-set method[15]. Later an ellipse fitting is applied to smooth and regulate the shape of segmented disc and cup boundary. Area of the disc and cup is found by finding number of white pixels in the results obtained from above methods. With the help of detected area, the cup to disc ratio (CDR) is calculated to suspect the glaucoma [15]. Finally clinical CDR is compared with the proposed methods. All the methods have been tested on publicly available DRIVE (Digital Retinal Images for Vessel Extraction) database created by J.J Staal et. al. [8].

II. IMAGE DATABASE

The images in the DRIVE database have been acquired using a Canon CR5 non-mydriatic 3CCD camera with a 45 degree field of view (FOV). Each image was captured using 8 bits per color plane at 768 by 584 pixels. The FOV of each image is circular with a diameter of approximately 540 pixels. For this database, the images have been cropped around the FOV. For each image, a mask image is provided that delineates the FOV. Each image has been JPEG compressed. The original JPEG compressed color photos in TIFF format. The set of 40 images has been divided into a training and a test set, both containing 20 images. All of the images contained in the database were actually used for making clinical diagnoses. To ensure the utmost protection of patient privacy, information that might allow the identity of a patient to be reconstructed has been removed, and we have no actual knowledge that the images could be used alone or in combination to identify any subject.

III. METHOD

In this work, the cup and the optic disc are segmented for calculation of CDR which helps in the determination of glaucoma. Here the green channel is used for processing, as the red channel is saturated and the blue channel is noisy. Often contrast is greater when the green channel alone is utilized in fundus image analysis as this enhances contrast between the back-ground and features, such as blood vessels and haemorrhages. Many processing and measurement tools, however,are written to operate on gray-scale image and this may need to be extracted from an RGB color image.

Pre-processing : There are several fundamental requirements for medical image filtering. First, it should preserve the important information from boundaries and detailed structures; second, it should efficiently suppress the noise in homogenous regions; and third, it should enhance the edge information. Pre-processing is the primary step in many systems in retinal image segmentation and analysis. The objective of the pre-processing is to enhance the retinal image for the segmentation of the optic disc and the optic cup for the accurate calculation of CDR. An anisotropic diffusion filtering have been used for pre-processing in this paper and have obtained satisfactory results.

Anisotropic Diffusion Filtering : Speckle is a form of multiplicative and locally correlated noise. Due to different visual angles during the image acquisition, the bright speckles are distributed over the images. Due to the curve retinal surface and the geometrical position of the light source and the camera, the peripheral part of the retina appears darker than the central region [20].Anisotropic diffusion is a non-linear filtering method, which tries to reduce the speckle of the image whereas preserving the contrast of the edges [21]. It is an edge sensitive extension of conventional adaptive speckle filter, in the same manner that the original Perona and Malik anisotropic diffusion [10].Anisotropic diffusion works properly in many kinds of images, mainly when the objects have uniform intensity regions.

The nonlinear partial differential equation (PDE) for smoothing image on a continuous domain:

$$\begin{cases} \partial I(x, y; t) / \partial t = div\,[c(q)\nabla I(x, y; t)] \\ I(x, y; 0) = I_0(x, y),\ (\partial I(x, y; t) / \partial \vec{n})\,|_{\partial\Omega} = 0 \end{cases} \quad (1)$$

Where is the ∇ gradient operator, div the divergence operator, c (q) the diffusion coefficient, and I0 is the initial image. and $\partial\Omega$ denotes the border of Ω, $\vec{n}$ is the outer normal to the $\partial\Omega$.

The diffusion coefficient is given by,

$$c(q) = \frac{1}{1 + [q^2(x,y;t) - q_0^2(t)] / [q_0^2(t)(1 + q_0^2(t))]} \quad (2)$$

q(x,y;t) is the instantaneous coefficient of variation determined by,

$$q(x,y;t) = \sqrt{\frac{(1/2)(|\nabla I| / I)^2 - (1/4^2)(\nabla^2 I / I)^2}{[1 + (1/4)(\nabla^2 I / I)]^2}} \quad (3)$$

and $q_0(t)$ is the speckle scale function.

Here, the instantaneous coefficient of variation q(x,y;t) serves as the edge detector in speckled imagery. The function exhibits high values at edges or on high-contrast features and produces low values in homogeneous regions. The speckle scale function $q_0(t)$ effectively controls the amount of smoothing applied to the image.

$$q_0(t) = \frac{\sqrt{\mathrm{var}[\ z(t)]}}{\overline{z(t)}} \quad (4)$$

Where var[z(t)] and $\overline{z(t)}$ are the intensity variance and mean over a homogeneous area at , respectively.

Segmentation of Optic Disc : The optic disc is the entrance of the vessels and the optic nerve into the retina. The optic disc region is usually of a brighter pallor or higher color intensity than the surrounding retinal area. To calculate the vertical cup to disc ratio (CDR), the optic cup and disc first have to be segmented from the retinal images. Optic disc segmentation is the primary task in the analysis and classification of normal and abnormal images. This study presents three approaches for disc segmentation, namely an edge detection method, optimal thresholding method, and manual threshold analysis.

Edge Detection Method: The green channel of the retinal image is extracted and filtered. After the preprocessing step that produces an image with uniform illumination, the next step is to remove the blood vessels and nerve fibers in the image, because these objects are not required in the segmentation process. The contrast of the blood vessels and the back ground is higher in the green channel. The morphological operation such as the closing is performed. The morphological functions are applied to do the pre-processing. In order to measure disc more accurately, the blood vessels in the image has to be removed. This is achieved by performing the closing operation. Closing is similar to dilation and it tends to enlarge the boundaries of foreground regions in an image and shrink background color holes in such regions. As closing only eliminate image details smaller than the structuring element used. The structuring element is selected such that it covers all possible vascular structures, at the same time preserving the edge of optic disc. The closing of *A* by *B* is obtained by the dilation of *A* by *B*, followed by erosion of the resulting structure by *B*:

$$A \bullet B = (A \oplus B) \ominus B \quad (5)$$

Thresholding is applied to the blood vessel removed cropped grayscale retinal image using the Otsu's method, which chooses the threshold to minimize the intraclass variance of the black and white pixels[12]. In this method, the optic disc is extracted by the edge command in MATLAB. The Canny method is specified for edge detection because the Canny algorithm can detect edges with noise suppressed at the same time. It uses two different thresholds (to detect strong and weak edges), and includes the weak edges in the output only if they are connected to strong edges. This method is therefore less likely than the others to be fooled by noise, and more likely to detect true weak edges. Morphological operation such as dilation is then performed. After performing the morphological functions the small holes gets filled and object boundary is smoothened.

Optimal Thresholding Method : Optimal thresholding method based on approximation of the histogram of an image using a weighted sum of two or more probability densities with normal distribution is used for initial thresholding of the retinal image. Histogram information derived from the source image is used to partition the brightest regions from background. It is observed that disc appears most contrasted in the green channel compared to red and blue channels in the RGB image. Therefore, only the green channel image is used for calculating the optimal threshold. Figure(1) shows the input green channel image and its histogram. It can be seen that the pixels corresponding to the optic disc and the optic cup belong to the higher intensity bars in the histogram. The diameter of the optic disc is in the range of 1.8 to 2mm. Based on the visual inference in a standard retinal image with 768 × 576 size with 20micron/pixel resolution, this prior information is used to calculate the threshold.To obtain an optimal threshold, histogram derived from the source image *I* is scanned from highest intensity value *l*2 to lower intensity value. The scanning stops at the intensity level *l1* which has atleast a thousand pixels with the same intensity. The initial threshold *Tk* for step *k*=1 is taken as the mean of *t*2 and *t1* resulting in subset of histograms. Formulation for the calculation of optimal threshold is given by the following pseudo code.

1.Initial estimate of Tk is calculated at step *k* as

$$T_k = \frac{l_1 + l_2}{2}$$

2. At step *k*, apply the threshold . This will produce two groups of pixels: *G*o consisting of all pixels belonging to object region and *G*b consisting of all pixels belonging to background region.
3. Compute the average intensity values and for the pixels in *G*o
4. Update the threshold as follows:

$$T_{k+1} = \frac{\mu_o^k + \mu_b^k}{2}$$

5. Repeat steps 2 through 4 difference in *T* in successive iterations is smaller than a predefined value.

Optimal threshold thus calculated results in maximization of gray level variance between object and background.

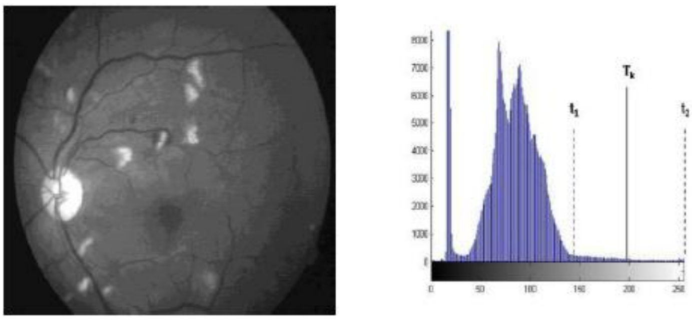


Fig 1: Selecting an optimal threshold; (a) Gray scale of green channel retinal image; (b) Corresponding histogram with initial threshold

Manual Threshold Analysis : In the manual threshold analysis method, the optic disc is extracted using the green channel as it is more easily discriminated in green image [11],as contrast is greater when the green channel alone is utilized. The complement of the grayscale image is taken. In the complement of an intensity image each pixel value is subtracted from the maximum pixel value and the difference is used as the pixel value in the output image. In the output image, dark areas become lighter and light areas become darker. The contrast of the image is effectively adjusted by mapping the values of the input intensity image to new values such that, by default, 1% of the data is saturated at low and high intensities of the input data. The grayscale image is converted into a binary image by manually adjusting the appropriate threshold. The complement of the threshold image is finally taken to obtain the optical disk**.**

Segmentation of Optic Cup: Compared to the extraction of the optic disc, optic cup segmentation is more challenging due to a cup's interweavement with blood vessels and surrounding tissues. This study presents an approach for cup segmentation, which is the threshold level set approach.

Threshold Level Set Approach: In this approach, the green channel of the input image is selected as the basis for further segmentation due to the optimum observed contrast between the cup and disc boundaries in this channel. Then the histogram of the green channel image is analyzed. 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 cup is set in order to extract the optic cup boundary from the extracted optic disk. Periodic re-initialization of the level set function is necessary but may not be an optimum

IV. ELLIPSE FITTING FOR OPTIC DISKAND OPTIC CUP

The intensity-weighted centroid method [22] is proposed to find an approximate initial point, This is found to give a good initial approximation for the initial disk and cup region. Then an ellipse fitting application is proposed, to smooth and regulate the shape of segmented disk and cup boundary. Intensity-weighted centroids can provide locations accurate to a fraction of a pixel.The centroid calculation involves the x-coordinate and y-coordinate **of** the pixel. Note that the first element of Centroid is the horizontal coordinate (or *x*-coordinate) of the center of mass, and the second element is the vertical coordinate (or *y*-coordinate). All other elements of Centroid are in order of dimension. 'MajorAxisLength','MinorAxisLength','Orientation'are determined to fit an ellipse around detected optic disk and the optic cup. 'MajorAxisLength' is a scalar specifying the length (in pixels) of the major axis of the ellipse that has the same normalized second central moments as the region. 'MinorAxisLength' is a scalar specifying the length (in pixels) of the minor axis of the ellipse that has the same normalized second central moments as the region. 'Orientation' is a Scalar; the angle (in degrees ranging from -90 to 90 degrees) between the *x*-axis and the major axis of the ellipse that has the same second-moments as the region.

V. RESULTS AND DISCUSSIONS

The main feature which is been considered here for identifying the vision impaired disease glaucoma is the cup-to-disk ratio (CDR), which specifies the change in the cup area [15]. Increase intra ocular pressure (IOP) results in increase in the area of the cup and this 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 ≤ 0.3, is considered as normal image [14]. We examine the mean square error (MSE), pixel signal to noise ratio (PSNR) and signal to noise ratio (SNR) to quantify the performance of the above pre-processing algorithms. Table (1) gives a study of the pre-processing methods. Fig.(1), shows the results of anisotropic filtering.
Given a noise-free $m \times n$ monochrome image I and its noisy approximation K, MSE is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \tag{6}$$

$$\begin{aligned} PSNR &= 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \\ &= 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right) \\ &= 20 \cdot \log_{10}(MAX_I) - 10 \cdot \log_{10}(MSE) \end{aligned} \tag{7}$$

Here, MAX_I is the maximum possible pixel value of the image.

$$\mathrm{SNR} = 10 \cdot \log_{10}\left[\frac{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)]^2}{\sum_{0}^{n_x-1}\sum_{0}^{n_y-1}[r(x,y)-t(x,y)]^2}\right] \tag{8}$$

Here, r(x,y) is a reference image t(x,y) is a test image and the two images have the size [n_x, n_y] respectively.

In fig.(3), the first row represents the results of edge detection method. The second row shows the results of optimal thresholding method. The third row represents simulation results of manual threshold analysis method.Table.2, compares the CDR value obtained from edge detection method optimal thresholding method, and finally manual threshold analysis for disc and threshold level set method for cup.

VI. CONCLUSIONS

The algorithm for the earlier identification of Glaucoma by estimating CDR was developed in this paper. The optic disc was segmented using the three methods namely edge detection method, optimal thresholding method and manual threshold analysis are proposed in the paper. For the cup, threshold level-set method is evaluated.The performance of various methods was evaluated by comparing the CDR Table(2). It was found that the manual threshold method and edge detection method provides better estimation of CDR.The method has been applied to nearly forty images and the CDR was correctly identified. Resizing of the images gave more accurate results for manual detection and optimal thresholding method. The implementation of the above said method would be more fruitful with the availability of more suitable data. The algorithm proposed in this paper has high value in clinic practice for automatic screening of early diagnosis of Glaucoma. This proposed method can be used as an adjunct tool by the physicians to cross check their diagnosis and hence can be an efficient tool for early detection of Glaucoma.

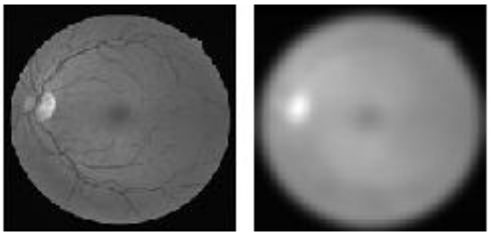
TABLE. 1.
Performance of Anisotropic Diffusion Filtering

RETINAL IMAGES	ANISOTROPIC DIFFUSION FILTER		
	MSE	PSNR	SNR
RI1	0.0013	76.9952	86.5794
RI2	0.0018	75.5748	85.4278
RI3	0.0010	78.0703	86.8274
RI4	0.0021	74.8766	84.2822
RI5	0.0010	78.0228	86.9998

TABLE. 2.
Comparison of CDR value of several methods

FUNDUS RETINAL IMAGES	EDGE DETECTION CDR	OPTIMAL THRESHOLD CDR	MANUAL THRESHOLD CDR
RI1	0.2105	0.2005	0.2914
RI2	0.2309	1.9801	0.2001
RI3	0.2515	0.2222	0.2807
RI4	0.2273	0.1862	0.2714
RI5	0.2672	0.2010	0.2650
RI6	0.2842	0.1978	0.2976
RI7	0.2001	0.1889	0.2983

RI8	0.3196	0.3011	0.4056
RI9	0.3342	0.3048	0.3564
RI10	0.3107	0.3009	0.4287



(a) (b)

Fig.1 Experiment results: (a) original image;
(b) preprocessed image

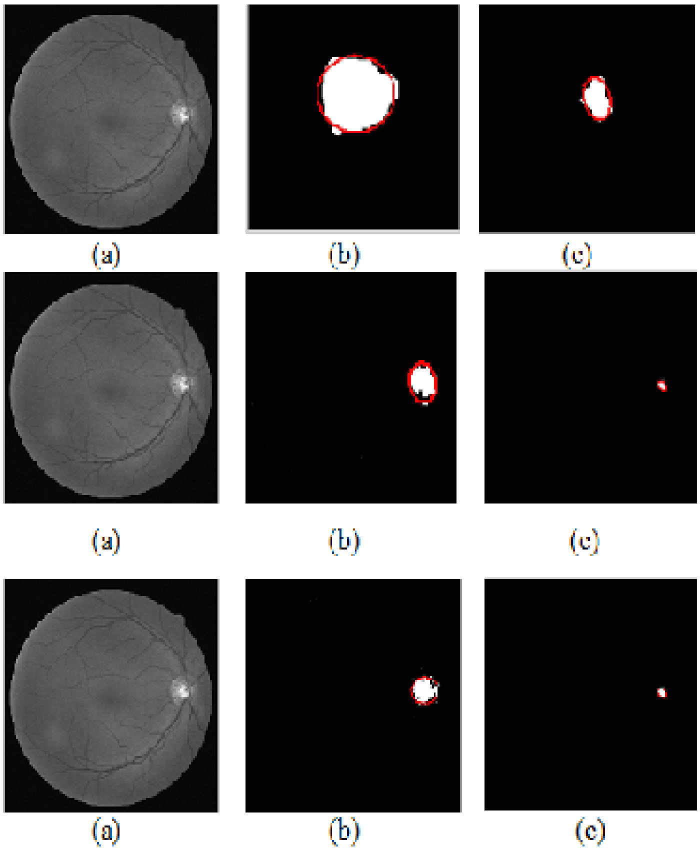


Fig.2 First row: Result from Edge Detection
Second row: Result from Optimal Thresholding
Third row:Result from Manual Threshold Analysis
Experiment results: (a) original image; (b) optic disk;
(c) optic cup

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