An Adaptive Threshold Based Algorithm for Optic Disc and Cup Segmentation in Fundus Images

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***Abstract*— This paper presents an image processing technique for segmentation of optic disc and cup based on adaptive thresholding using features from the image. The proposed algorithm uses the features obtained from the image, such as mean and standard deviation, to remove information from the red and green channel of a fundus image and obtain an image which contains only the optic nerve head region in both the channels. The optic disc is segmented from the red channel and optic cup from the green channel respectively. The threshold is determined from the smoothed histogram of the preprocessed image. The results of the proposed algorithm are compared with the images that are marked by doctors. The accuracy of the algorithm is good and is computationally very fast. The proposed method can be used for screening purpose.**

Keywords—* *Glaucoma, optic disc, optic cup, fundus image processing.

I. Introduction

Glaucoma is defined as optic neuropathy characterized by recognizable changes in the structure of optic disc and retinal fibre structure. It is also characterized by loss of vision and optic nerve cupping of the optic disc. The cup-to-disc ratio (CDR) is used to measure the progression of Glaucoma. The risk of glaucoma increases when the intra-ocular pressure (IOP) increases. The optic nerve head (ONH) structure changes and the neuroretinal rim starts to diminish. The axons degenerate and the cup size increases.

Glaucoma can be detected by using a visual field test and which can be then followed by CDR calculation. The CDR increase causes a decrease in the area of the neuro-retinal rim.

Some work using image processing techniques has been done on Fundus images for the detection of Glaucoma. The neuroretinal rim and OD area along different sectors of OD as a function of age are used for detection of Glaucoma [1]. The damages caused during glaucoma in retinal nerve fiber layer are detected using computer aided detection (CAD) and Gabor filtering [2]. A number of features such as cup-to-disc ratio (CDR), ratio of the distance of optic nerve head shift to the diameter of OD, and the ratio of the area of blood vessels in the inferior-superior side to the nasal-temporal side (ISNT) were used to classify the available fundus images as normal and glaucoma images by using a neural network classifier [3]. Based on line profile analysis, the cup-to-disc ratio is measured in retinal images [4]. The glaucoma detection and classification was performed by using principal component analysis and LDA [5]. Various image processing techniques are addressed for glaucoma detection by evaluating CDR for preprocessed fundus images [6]. An automatic segmentation technique based on mathematical morphology has been used for glaucoma diagnosis [7]. A double threshold technique followed by Hough Transform has been used to segment the optic disc and cup for Glaucoma identification [8]. The optic disc and cup boundaries are distinguished using texture features [9]. All these works have proposed methods of detection, but there is still need for more accurate and efficient methods for detection of optic disc and cup.

The main contribution of the paper lies in the optic cup and disc segmentation from optic nerve head using an algorithm which is completely adaptive and threshold based. A very less amount of information is left in a Gaussian curve if a threshold value is set to more than the sum of mean and 3 times the standard deviation. Utilizing this information, an algorithm has been proposed where threshold based segmentation of optic disc and cup is done on the fundus images. Since, the detection of threshold value is adaptive in nature, every image is treated independently and the accuracy of detection disc and cup is increased.

The remaining paper is sectioned as follows: Section II describes the methodology used for the segmentation of optic cup and disc from the fundus images. Section III contains experimental results and Section IV draws a conclusion to the paper work and future work.

II. Proposed Methodology

A retinal fundus image is an image which contains the interior surface of the eye, which includes retina, optic nerve head, macula, fovea and blood vessels. The interior surface of the eye has a bright circular region called as optic nerve head (ONH). The blood vessels and optic nerve fibers exit the retina through ONH. The ONH further contains optic disc and optic cup. The optic cup is the brightest region inside ONH. In a normal eye, the ONH has only optic disc. However, for a glaucoma affected eye, the cupping of disc starts and optic cup is formed. The fundus image labeled with different parts is shown in Fig. 1 [10].

A colour fundus image comprises of red, green and blue channels. The optic disc is mostly of red, orange or yellow colour and because of this property it can be easily distinguished in the red channel. After studying a large number of images, it was observed that the green channel has a high contrast and this property of green channel is used to distinguish the optic cup from the optic disc.

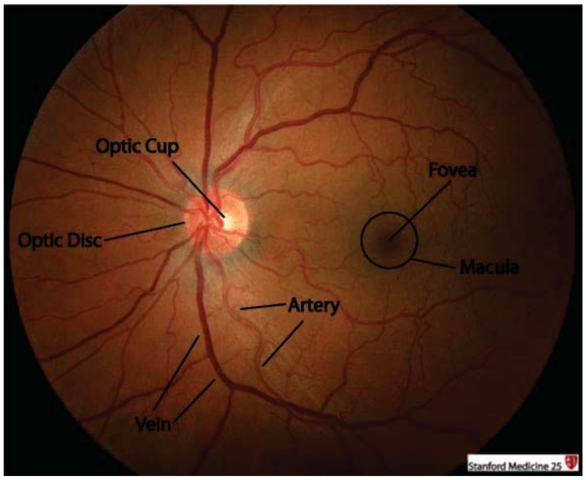


Fig. 1. Retinal Fundus Image

The histogram of a fundus image is used to find the threshold value for segmentation of various parts of the fundus image. The optic disc and cup being the brightest part in a fundus image, constitutes the pixels with a high gray value. Some preprocessing steps are performed on the fundus images to make them ready for the algorithm.

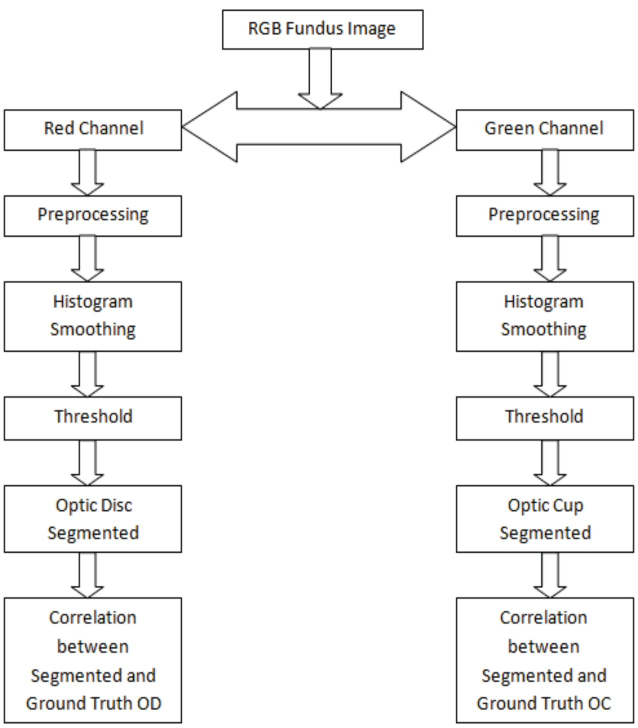


Fig. 2. Flowchart for the segmentation of optic disc and cup

Fig. 2 shows the flowchart for the segmentation of the optic cup and disc from a RGB image. As described earlier, the optic disc can be easily distinguished in a red channel and optic cup can be distinguished in a green channel, the red and green channels of the fundus image are extracted. These channels are preprocessed to make the image ready for the direct implementation of the algorithm. After preprocessing, a threshold is selected from the histogram of the preprocessed images. This value of threshold is applied to the images for segmentation. The output of the threshold gives a binary image. The number of white pixels in the binary image obtained after segmentation of disc gives the disc area and the number of white pixels in the optic cup segmented binary image gives the cup area.

A. Preprocessing

After analyzing a number of images, it is observed that the optic disc can be distinguished from the background in a red channel and the optic cup can be distinguished from the background and optic disc in a green channel. The red and green channels were made ready for thresholding by performing some preprocessing steps.

The optic disc and optic cup constitute a high gray value levels in a fundus image. If all the remaining pixels are removed from red and green channel, then only optic disc and cup are obtained from the respective channels.

The images are made ready for applying threshold by removing the information from the both the channels. The information can be removed by simply subtracting the mean and standard deviation from the channels.

The image obtained after removing information from the channels contains only the optic nerve head region in both the channels.

Mean of an image is obtained by dividing the sum of all the pixels by the number of pixels, i.e.

$$\bar{A} = \frac{1}{M * N} * \sum_{i=1}^{M} \sum_{j=1}^{N} A(i, j) \tag{1}$$

The mean of an image represent that most of the pixels in the image have this particular value of gray level or are closer to this value.

Standard Deviation of an image shows how the entire set of pixels is related to the mean value of the entire set of pixels, i.e.

$$\sigma = \sqrt{\frac{1}{M * N} * \sum_{i=1}^{M} \sum_{j=1}^{N} (A(i, j) - \bar{A})^2} \tag{2}$$

Where, M = no of rows of pixels in a gray scale image

N = no of columns of pixels in a gray scale image

A = gray scale image

Ā = mean of a gray scale image

σ = standard deviation of a gray scale image

The standard deviation represents the variation of the gray levels from the mean value.

B. *Optic Disc Segmentation*

The preprocessed red channel is used to segment the optic disc. The histogram of the preprocessed red channel is plotted and smoothed using a Gaussian window of size m×1. A threshold value for segmentation of optic disc is then formulated using this smoothed histogram. The threshold to segment the optic disc is given as:

$$T1 = (0.5*m) - (2*\sigma_G) - (\sigma_{RI}) \quad (3)$$

Where, T1 = threshold for segmentation of optic disc

m = size of Gaussian window

σ_G = standard deviation of Gaussian window

σ_{RI} = standard deviation of the preprocessed red channel

The image after applying this threshold T1 on the red channel gives a binary image which contains segmented optic disc.

The segmented optic disc is subjected to morphology operations. Firstly, a morphological closing is performed followed by morphological opening. A disk shaped structuring element is used. The segmented optic disc after threshold and the optic disc obtained from the gray scale image marked with ground truth by doctors are used for correlation. A correlation coefficient is found between both the images.

C. *Optic Cup Segmentation*

The preprocessed green channel is used to segment the optic cup. The histogram of the preprocessed green channel is plotted and smoothed using the same Gaussian window of size m×1 used above to smooth the histogram of preprocessed red channel. A threshold value is then formulated from this smoothed histogram of preprocessed green channel for segmentation of optic cup. The threshold is given as:

$$T2 = (0.5*m) + (2*\sigma_G) + (2*\sigma_{GI}) + (\mu_{GI}) \quad (4)$$

Where, T2 = threshold for segmentation of optic cup

m = size of Gaussian window

σ_G = standard deviation of Gaussian window

σ_{GI} = standard deviation of the preprocessed green channel

μ_{GI} = mean of the preprocessed green channel

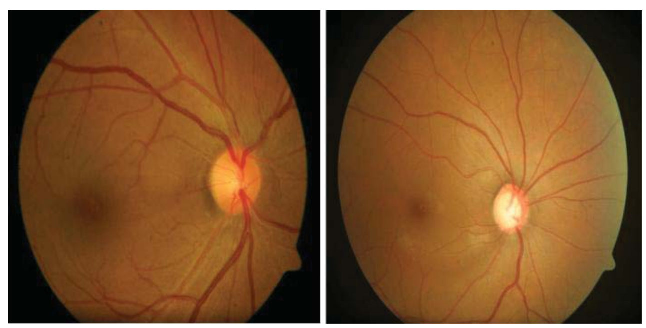
The image after applying this threshold T2 on the green channel gives a binary image which contains segmented optic cup.

The segmented optic cup is subjected to morphology operations. Firstly, a morphological closing is performed followed by morphological opening. A disk shaped structuring element is used. The optic cup segmented after threshold and the optic cup obtained from the gray scale image with ground truth marked by doctors are correlated to find the correlation coefficient.

III. EXPERIMENTAL RESULTS

The images used for experimentation were obtained from a local hospital. A total of 63 images were used for the segmentation. The images were stored in JPEG format. The resolution of the images was 2544 × 1696. The doctors have photographed and certified the images. The data has been approved by doctors for the research purpose. The images were photographed using a fundus camera and it captures the inner surface of the eye. The ground truth was marked by doctors in the images. This ground truth showed the optic disc and optic cup boundaries in a retinal fundus image. The ground truth was used to compare the results with the segmented results and a correlation was established between the images.

Fig. 3 shows a sample of retinal fundus image. Fig. 3(a) shows a normal fundus image. The image can be regarded as normal since the cupping of optic disc is not visible. The central bright portion is optic nerve head. The blood vessels and nerve fibres exit from the eye through this point. The optic nerve head has optic disc. If an eye is glaucoma affected then the disc starts cupping. The cupping can be observed as brighter pixels than the optic disc pixels inside the optic disc. Fig. 3(b) shows a glaucoma affected eye. From the figure, it is clear that there are brighter pixels present inside the optic disc, which are considered to be part of optic cup. The number of pixels of cup divided by the number of pixels of disc gives the cup-to-disc ratio.



(a) (b)

Fig. 3. Fundus image (a) Normal Eye (b) Glaucomatous Eye

Fig. 4 shows a sample of histogram of a single sample. Fig. 4(a) is the histogram of the red channel of a sample image. The intensity of the gray levels is shown on horizontal axis while the number of pixels having a gray level is shown on the vertical axis. The different peaks in a histogram show the different parts of the inner eye. The first peak is considered to be that of background pixels as they have low gray level intensities while the last peak is considered to be of the optic disc and cup as they have bright pixels with a high gray level intensity. Fig. 4(b) is the histogram of the gray level intensities versus the number of pixels of the preprocessed red channel. The threshold, T1, for segmentation of optic disc is shown in the figure. Fig. 4(c) is the histogram of the green channel of a sample image. Fig. 4(d) is the histogram of the preprocessed green channel. The threshold for segmentation of optic cup is shown in the figure as T2.

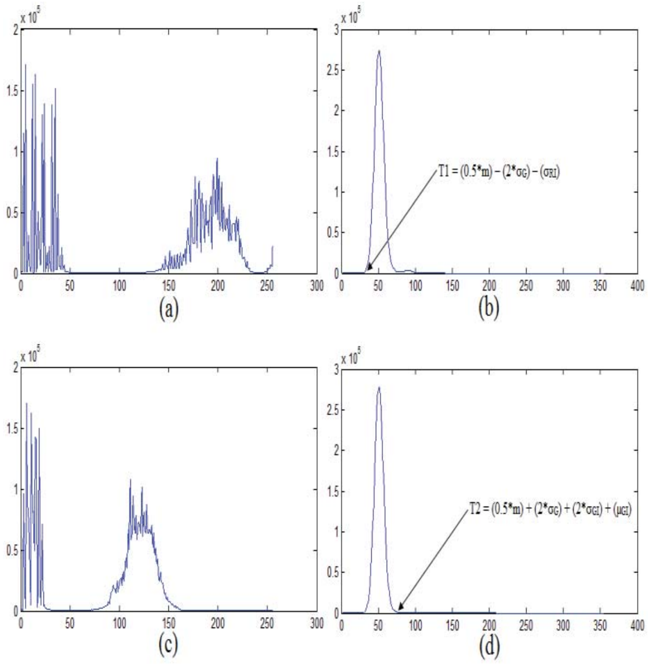


Fig. 4. (a) Histogram of Red Channel (b) Smoothed Histogram of Preprocessed Red Channel (c) Histogram of Green Channel (d) Smoothed Histogram of Preprocessed Green Channel

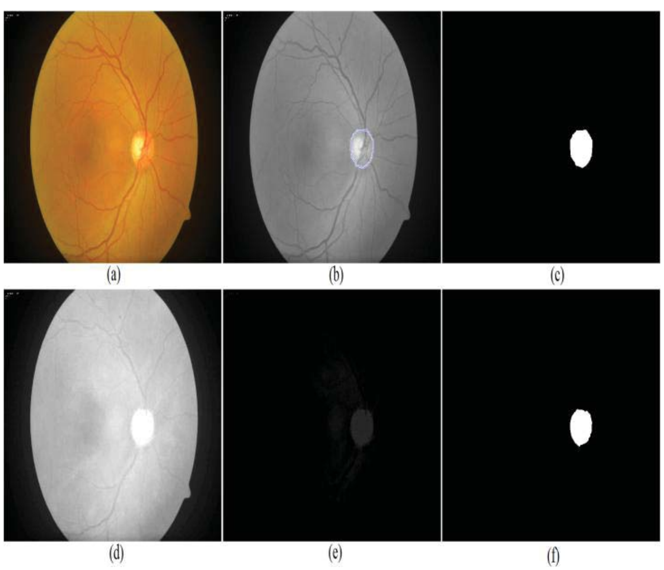


Fig. 5. (a) Colour Fundus Image (b) Ground Truth marked Gray Scale Image (c) Segmented Ground Truth (d) Red Channel (e) Preprocessed Red Channel (f) Segmented Optic Disc

Fig. 5 shows the results involved in the segmentation of optic disc. Fig. 5(a) shows the input colour fundus image. Fig. 5(b) is a gray scale image of the input fundus image with marked ground truth. The image shows the boundaries marked by the doctor for the optic disc in a gray scale image. Fig. 5(c) is the segmented disc from the marked ground truth image. The boundaries shown in the ground truth marked image are used to segment the optic disc. Fig. 5(d) is the red channel of the input image which will be used for optic disc segmentation. Fig. 5(e) is the preprocessed red channel. The information has been removed from the red channel and only the regions with bright pixels are left. This preprocessed image is thresholded and gives a binary image which contains only optic disc. Fig. 5(f) shows the optic disc after segmentation using the algorithm and morphological operation performed on the binary image obtained after thresholding.

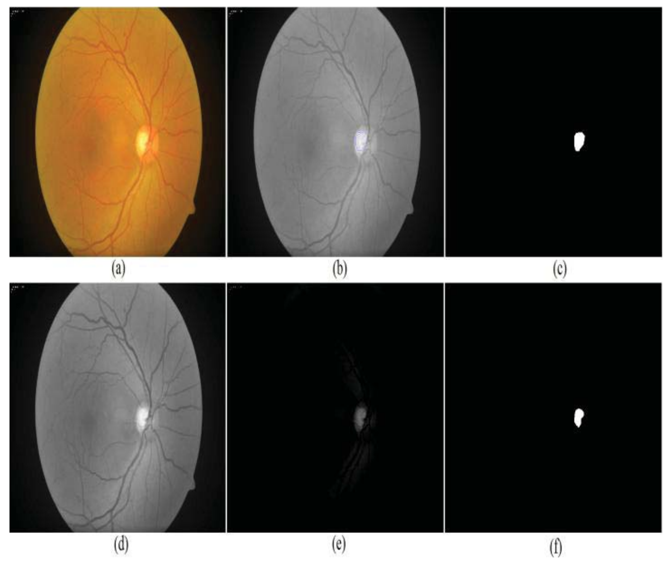


Fig. 6. (a) Colour Fundus Image (b) Ground Truth marked Gray Scale Image (c) Segmented Ground Truth (d) Green Channel (e) Preprocessed Green Channel (f) Segmented Optic Cup

Fig. 6 shows the results involved in the segmentation of optic cup. Fig. 6(a) shows the input colour fundus image. Fig. 6(b) is a gray scale image of the input fundus image with marked ground truth. The image shows the boundaries marked by the doctor for the optic cup in a gray scale image. Fig. 6(c) is the segmented cup from the marked ground truth image. The boundaries shown in the ground truth marked image are used to segment the optic cup. Fig. 6(d) is the green channel of the input image which will be used for optic cup segmentation. Fig. 6(e) is the preprocessed green channel. The information has been removed from the green channel and only the regions with bright pixels are left. This preprocessed image is thresholded and gives a binary image which contains only optic nerve head. Fig. 6(f) shows the optic cup after segmentation using the algorithm and morphological operation performed on the binary image obtained after threshold.

Table I shows the comparison between the segmented results and the ground truth images marked by the doctor. The comparison is done by finding the correlation coefficients between the segmented images marked with ground truth and the segmented images obtained from the algorithm. The morphological operations such as closing and opening are performed on the segmented optic disc and cup. From the correlation coefficients obtained from both the cases, it can be concluded that the results were better when morphological operation is performed on the segmented disc and cup. The structuring element used to perform the morphological closing and opening is disk shaped. For better results, the size of the structuring element used should be more than the thickness of the primary blood vessel.

TABLE I. CORRELATION COEFFICIENTS BETWEEN SEGMENTED AND GROUND TRUTH OPTIC DISC AND OPTIC CUP

Sample	**Correlation Coefficient Between (Without Morphology)**		**Correlation Coefficient Between (With Morphology)**	
	Segmented OD And Ground Truth OD	***Segmented OC And Ground Truth OC***	***Segmented OD And Ground Truth OD***	***Segmented OC And Ground Truth OC***
Sample 1	0.9727	0.7462	0.9628	0.7300
Sample 2	0.9384	0.8663	0.9426	0.8927
Sample 3	0.8262	0.8525	0.7770	0.8754
Sample 6	0.9042	0.8701	0.9486	0.8740
Sample 6	0.8329	0.8719	0.8715	0.8651
Sample 6	0.9570	0.7802	0.9606	0.8439
Sample 7	0.7760	0.7514	0.8221	0.7936
Sample 8	0.8827	0.8050	0.9431	0.8715
Sample 9	0.9633	0.8467	0.9414	0.8928
Sample 10	0.8863	0.8929	0.9156	0.8829

IV. CONCLUSION

The proposed methodology to segment the optic disc and cup from a fundus image is accurate and efficient. The common challenge in glaucoma detection is the accurate segmentation of optic disc which can be affected due to presence of peri-papillary atrophy (PPA). However, in the proposed work, this shortcoming is overcome as only the brighter pixels will be threshold.

However, when applied on the images from the local hospital, it was observed that the algorithm failed on 5 images out of 63 images. The proposed algorithm segmented the optic disc and cup to an accuracy of 92.06%. The algorithm is computationally fast and produces the segmentation of both disc and cup in 3.313 seconds. This computation time is obtained on a PC installed with MATLAB R2008a software.

The proposed algorithm was also applied on the MESSIDOR database also and it produced satisfactory results on those images as well.

The proposed algorithm is an efficient framework and it can be used for automatic diagnosis of glaucoma in screening programs.

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