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Research Article

Glaucoma detection using Cup-to-Disc Ratio assessment

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Abstract

Optic cup and disc segmentation is critical for automated cup-to-disk ratio measurement and hence computeraided diagnosis of glaucoma. Earlier, segmentation using the concept of r-bends resulted Various methods used for Optic Cup and Disc segmentation are CNN, mean curvature and Gabor texture energy features, intensity based cup segmentation, deformable models, template matching and morphological procedures, statistical measures and Superpixel Classification. As a result, a new methodology using Colour based fundus image segmentation and segmentation approach using Adaptive threshold based segmentation is proposed. The segmentation of Optic Disc has been done using red channel whereas that of Optic Cup has been done using green channel of an RGB image. The threshold is ascertained from the smoothed histogram of the pre-processed image. In colour based segmentation approach, a mask based on intensity values of input image is created and image is segmented accordingly. These approaches would help overcome the challenges faced using previous methodologies. The dataset comprises of a set of 50 retinal fundus images alongwith its ground truth provided by the doctors.

Keywords: *Glaucoma; Cup-to-Disc Ratio (CDR); Colour Spaces Segmentation; Adaptive Threshold based Segmentation*

Introduction

The word glaucoma itself originates from ancient Hellenic word, meaning ‘clouded or blue-green hue’, apparently which describes a person with a dilated cornea or who is steadily developing a cataract, both of which may be affected by chronic or long term increase in the intraocular pressure of the eye [1].

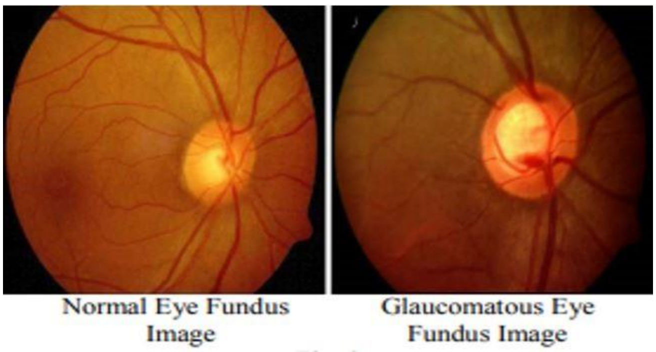


Fig. 1. Normal Eye Fundus Image and Glaucomatous Eye Fundus Image [1]

It is a category of diseases which includes the optic nerve to be vandalized leading to irreversible loss of vision. In majority of the cases, this loss is due to immense increase of pressure within the eye. Aqueous humor is the vitreous fluid generated by the eye which is secreted by ciliary body into the posterior chamber- a section between the iris and the lens. It drains through trabecular mesh network [2]. In a healthy eye, the rate of secretion is linked to the rate of drainage. Glaucoma arises when drainage canal is partially or fully blocked which leads to the increase in pressure, called intraocular pressure which causes losses to the optic nerve [3]. This project has been sponsored by National Institute of Ophthalmology (NIO). One of the primary physiological characteristics used for identification of glaucoma is the optic cup to disc ratio. Fig. 2 describes the Region of Interest (ROI) that contains the Optic Disc and the Optic cup.

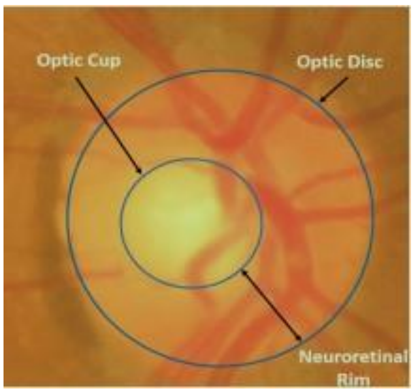


Fig. 2. Fundus image showing O.D and O.C with their boundary contours shown in blue [10]

The C/D ratio shows the depression in the optic disc in which case the neural tissue is absent and compared with usual optic disc size [6]. There are several other techniques used for Glaucoma detection in the work done by other researchers. Using Region of Support concept, vessel bends are detected in order to detect Glaucoma [1]. Mean curvature and Gabor energy texture features have also been used [2]. Intensity based Optic Cup segmentation [3] and template matching techniques [4] have been incorporated. Optic Disc and Cup segmentation using U-Net CNN yields commmendable accuracy [6]. Based on centre surround statistics, Superpixel classification categorized whether a pixel is a disc or non-disc [7]. Segmentation has been done using modified multi-thresholding [8]. Optic Cup has been segmented by using Polar transform [9]. Although these studies have put forward various techniques for segmentation and detection, there is still requirement of accurate cup segmentation.The prominent offering by this paper lies in the segmentation of Optic disc and cup by means of thresholding and colour transformation techniques. These algorithms are based upon the fact that colour channels provide crucial data in segmentation process. Consequently, leading to efficient CDR evaluation and finally accurate Glaucoma detection.

Literature Survey

The method captures OD boundary in a unified manner for both normal and challenging cases without imposing any shape constraint on the segmentation result, unlike the earlier methods [1]. The proposed CTCRW algorithm for OD segmentation incorporates mean curvature, Gabor texture energy features with multiple orientations in the RW weight formulation. The intensity adjustment around the OD centre in the pre-processing step and careful selection of K number of foreground and background seeds add robustness to the method [2]. An intensity based segmentation of the OC is obtained by applying a statistical deformable model. Vessel bendings in the temporal side and blood vessel boundaries in the nasal side are then detected and used to fine tune the OC boundary. Proposed method can achieve a Dice coefficient of 0.83 for the segmentation and a mean absolute error of 0.096 for the cup-to-disk ratio [3]. The Optic Disc centers diameter identified through this method are near close to ground truth provided by the ophthalmologist experts. The proposed system achieves 98.7 percent accuracy in locating the Optic Disc [4]. The proposed algorithm segmented the optic disc and cup to an accuracy of 92.06 percent [5]. The proposed model can be used for batch predictions as well as online predictions. Hence, can be used on large number of fundus images and give results within short time [6]. This technique achieves areas under curve of 0.800 and 0.822 in two data sets, which is higher than other methods. The methods can be used for segmentation and glaucoma screening [7]. On applying multi-level thresholding on the image, followed by morphological opening to remove noise, the segmented OD is obtained. The algorithm shows an accuracy of 94 percent over a database of 50 Images [8]. The result is evaluated using three indicators which are the F-score, Boundary localization error, and overlap. The performance of our OC segmentation is 87.7, 86.2, and 12.3, respectively [9].

Proposed Methodology

A. Schematic representation of Optic Disc and Cup segmentation algorithm

The architecture defines the flow of segmentation process initiating with the extraction of red and green channels. Initially, the fundus images are preprocessed to remove unwanted intensity effects. Histogram smoothing followed by thresholding results into efficient Optic Disc and cup segmentation.

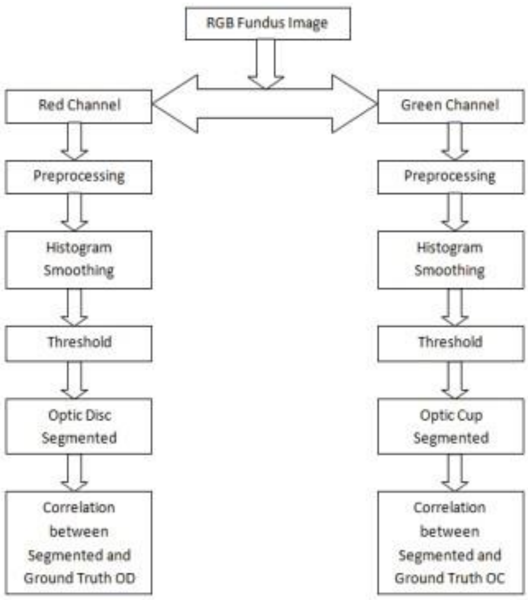


Fig. 3. Flowchart of Segmentation of Optic Disc and Optic Cup [5]

B. Algorithms

1) Color plane based segmentation technique: In the most common color space, RGB (Red, Green, Blue), colors are represented in terms of their red, green, and blue components. In more technical terms, RGB describes a color as a tuple of three components. Each component can take a value between 0 and 255, where the tuple (0, 0, 0) represents black and (255, 255, 255) represents white. RGB is considered an "additive" color space, and colors can be imagined as being produced from shining quantities of red, blue, and green light onto a black background. Following examples show the colours and their respective RGB representations:

- 255, 0, 0: Red
- 255,128,0: Orange
- 255,153,255: Pink

RGB is one of the five major color space models, each of which has many offshoots. There are so many color spaces because different color spaces are useful for different purposes. CMYK is useful because it describes the color combination required to produce a color from a white background. While the 0 tuple in RGB is black, in CMYK the 0 tuple is white. In reality, color is a continuous phenomenon, meaning that there are an infinite number of colors. Color spaces, however, represent color through discrete structures (a fixed number of whole number integer values), which is acceptable since the human eye and perception are also limited. Color spaces are fully able to represent all the colors we are able to distinguish between.

2) Adaptive threshold based segmentation technique: 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.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 cupto-disc ratio (CDR) is used to measure the progression of Glaucoma. The risk of glaucoma increases when the intraocular 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. 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.

3) 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.

$$\overline{A} = \frac{}{M \times N} {}_{i=0 \quad j=0} \; A(i,j)$$

$$\sigma = \sqrt{\frac{1=}{M \times N} {}_{i=0 \quad j=0} \; A(i,j) - \overline{A}}$$

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.
where,

M = no of rows of pixels in a grayscale image
N = no of columns of pixels in a grayscale imageA = grayscale image l = mean of a grayscale image σ = standard deviation of a grayscale image

4) 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. 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:
$T1 = (0.5\times m) - (2\times \sigma_G) - (\sigma_{R1})$

where,
T1 = threshold for segmentation of optic disc m = size of Gaussian window σ_G = standard deviation of Gaussian window σ_{R1} = standard deviation of the pre-processed 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 morphological 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.

5) 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 mA—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:

$T2 = (0.5\times m)+(2\times \sigma_G)+(2\times \sigma_{G1})+(\mu_{G1})$

where,

T2 = threshold for segmentation of optic cup m = size of Gaussian window Γ_G = standard deviation of Gaussian window σ_{G1} = standard deviation of the preprocessed green channel μ_{G1} = 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.

Results and Discussions

A. Implementation results on Fundus images

In figure 4, one of the retinal fundus images has been taken as an input. The segmentation of Optic Disc and Optic Cup is performed upon the same.

Fig. 4. Input Fundus Image

In figure 5, the segmentation of Optic Cup has been performed using Colour plane based segmentation technique. The contours of the same have been marked upon the input fundus image. In figure 6, the Optic Disc has been segmented using the same technique mentioned above. The boundary of the Optic Disc has been plotted upon the original image. Figure 7 displays both the Optic Disc and Optic Cup boundaries that have been marked upon the same image. Figure 8 displays the calculation of Cup-to-Disc ratio has been performed using the Segmentation results.

B. Statistical Analysis

1) Analysis of Segmentation of Optic Disc: Fig. 9 represents histogram of red channel of image:

The resolution of the image: (134, 130) Number of pixels in the image: 17420

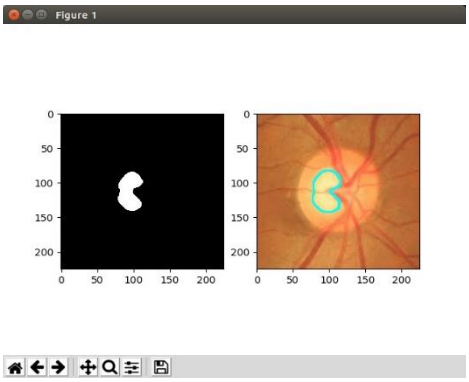


Fig. 5. Segmented and marked Optic Cup

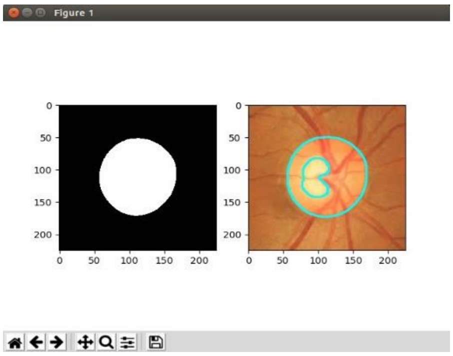


Fig. 6. Segmented Optic Disc

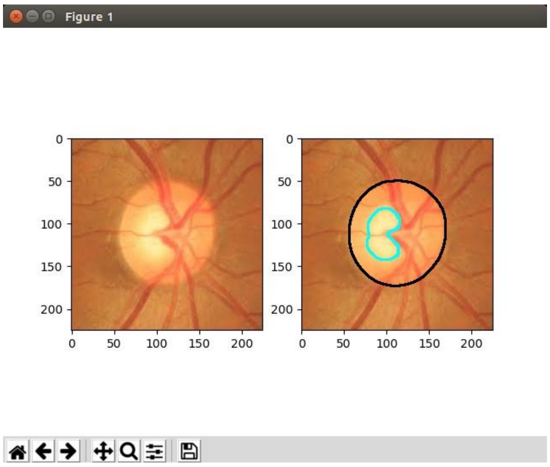
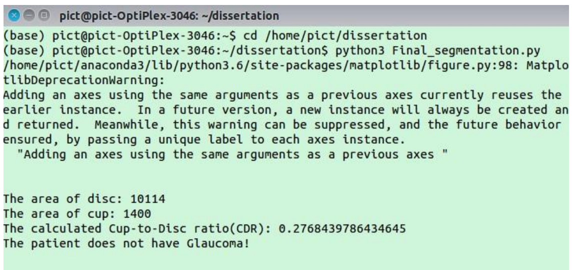


Fig. 7. Segmented Optic Disc and Optic Cup



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(base) pict@pict-OptiPlex-3046:~$ cd /home/pict/dissertation
(base) pict@pict-OptiPlex-3046:~/dissertation$ python3 Final_segmentation.py
/home/pict/anaconda3/lib/python3.6/site-packages/matplotlib/figure.py:98: Matplo
tlibDeprecationWarning:
Adding an axes using the same arguments as a previous axes currently reuses the
earlier instance.  In a future version, a new instance will always be created an
d returned.  Meanwhile, this warning can be suppressed, and the future behavior
ensured, by passing a unique label to each axes instance.
  "Adding an axes using the same arguments as a previous axes "


The area of disc: 10114
The area of cup: 1400
The calculated Cup-to-Disc ratio(CDR): 0.2768439786434645
The patient does not have Glaucoma!
```

Fig. 8. Calculated CDR for the input fundus image

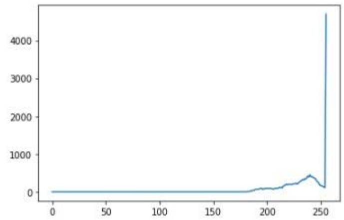

Fig. 9. Histogram of red channel of the input image

Highest pixel intensity in the image: 255
Mean of the image is: 148.96
Standard Deviation of the image: 37.36
Fig. 10 represents histogram of pre-processed image:

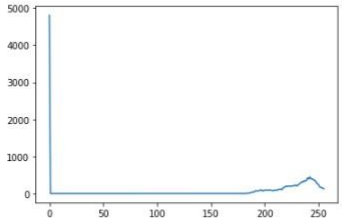

Fig. 10. Histogram of pre-processed input image

Maximum pixel intensity after pre-processing: 255 Fig. 11 represents histogram of Gaussian blurred image:

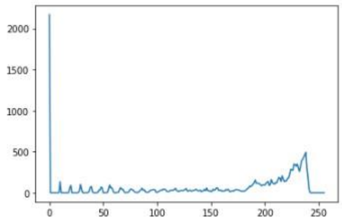

Fig. 11. Histogram of Gaussian blurred input image

The calculated threshold value for segmentation: 181.25

2) Analysis of Segmentation of Optic Cup: Fig. 12 describes histogram of green channel of image: The resolution of the image: (134, 130)
Number of pixels in the image: 174204

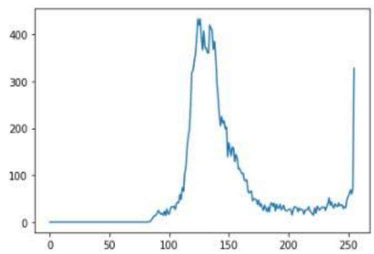

Fig. 12. Histogram of green channel of the input image

Highest pixel intensity in the image: 255
Mean of the image is: 235.88
Standard Deviation of the image: 18.31
Fig. 13 describes histogram of pre-processed image:

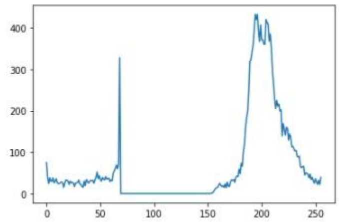

Fig. 13. Histogram of input image pre-processed in green channel

Fig. 14 describes histogram of Gaussian blurred input image in green channel:

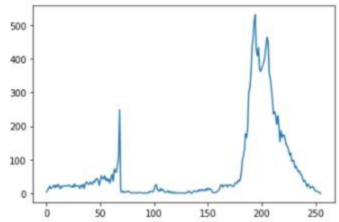

Fig. 14. Histogram of Gaussian blurred image

Result Analysis

As described earlier, there were two techniques used for segmentation namely, Colour plane based segmentation technique and Adaptive thresholding technique. The Adaptive thresholding technique achieved to gain more success rate compared to Colour Transformation technique. The bar chart in Fig. 15 describes comparative analysis of results attained using the two described segmentation techniques. The reason behind the failure in Colour transformation technique is that the fundus images given as an input vary in illumination and other lighting effects. On the other hand, Adaptive thresholding technique is independent of illumination barriers, making the system more robust and hence proved to attain better results.

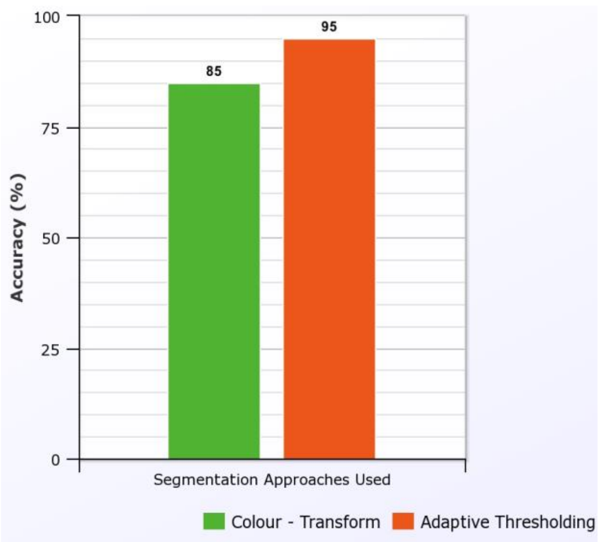

Fig. 15. A line chart displaying accuracy analysis using various classifiers

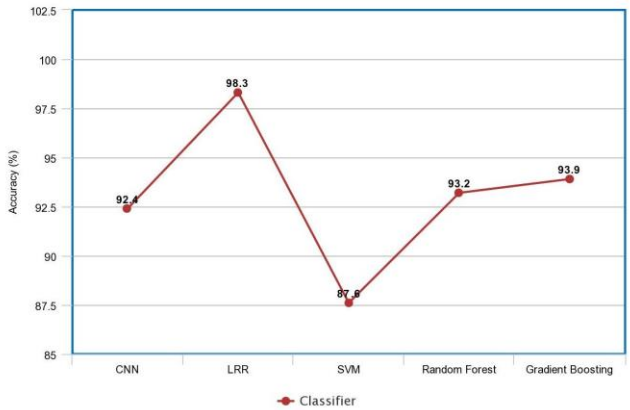

Fig. 16. A bar chart displaying accuracy obtained using he described segmentation techniques.

Followed by segmentation of the Optic Disc and Optic Cup, the extracted features were passed as an input to supervised classifiers. Fig. 16 describes analyses the accuracies obtained using different classifiers. The classifiers used were namely, Convolutional Neural Networks (CNN), Linear regression, Support Vector Machine (SVM), Random Forest and gradient Boosting. Amongst all the mentioned classifiers, LRR proved to yield the highest accuracy, followed by CNN.

Conclusions

100% accurate segmentation of Optic Disc and Optic Cup faces a challenge. Extraction of Optic Disc and Optic Cup has been done using Colour plane based segmentation and Adaptive thresholding methods.

In the future, more robust methods for better accuracy may be used. Also an improvement in the Optic disc and cup segmentation can be achieved without human intervention, as the same presently faces a challenge.

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