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A Novel Combined Color Channel and ISNT Rule Based Automatic Glaucoma Detection from Color Fundus Images

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Abstract

Background/Objectives: Glaucoma is an eye disease causing optic nerve damage and subsequently leading to progressive, irreversible vision loss. The need for early detection of glaucoma arises due to its asymptomatic and irreversible vision loss nature. For large scale screening of glaucoma, Color Fundus Images (CFI) is suitable due to its cost effectiveness. Therefore many works have been done toward automated glaucoma detection system by analyzing the Optic Nerve Head (ONH) from the CFI and calculating the Cup-to-Disk Ratio (CDR), a key indicator of glaucoma. **Methods/Statistical Analysis:** Unlike past works which relies on a single color channel for extracting the Optic Disk (OD) and Optic Cup (OC) used in CDR calculation, we propose a novel combined color channel and ISNT rule based automated glaucoma detection. **Findings:** The result shows that the proposed method betters single channel based giving an overall efficiency of more than 97%. **Applications/Improvements:** Screening of glaucoma at large scale by manual means requires skilled ophthalmologists which are scarce and also the cost of screening is very costly. Hence Computer-Aided Diagnosis (CAD) based automated glaucoma screening using CFI would be apt for large scale screening.

Keywords: Cup-to-Disk Ratio, Color Fundus Images (CFI), Feature Extraction, Glaucoma

1. Introduction

Glaucoma is a progressive optic neuropathy with asymptomatic vision loss in its early stages. It is caused by increased Intra-Ocular Pressure (IOP)[1]. Glaucoma is the second most common cause of blindness worldwide[2]. Due to the fact that glaucoma has no early symptoms and vision loss due to glaucoma cannot be regained back makes early detection of glaucoma a must for the prevention of vision loss due to the disease. Screening of glaucoma at large scale by manual means requires skilled ophthalmologists which are scarce and also the cost of screening is very costly. Hence Computer-Aided Diagnosis (CAD) based automated glaucoma screening using CFI would be apt for large scale screening. Glaucoma can be detected by analyzing the ONH and segmenting the optic disc and optic cup and calculating the CDR. The CDR value of a normal eye is <0.3. The cup size increases due to increased IOP in case of glaucoma. The CDR value in case of glaucoma is high due to increased cup region. Hence CDR acts as a key measure for glaucoma detection. Figure 1 show CFI of a normal eye, and features of interest and CDR calculation for glaucoma detection.

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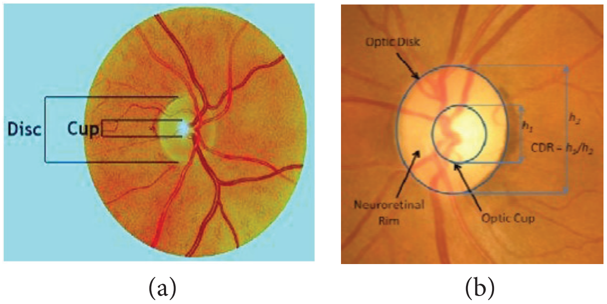

Figure 1. L to R: (a) CFI of a normal eye, (b) CDR calculation highlighted in CFI.

The main feature for glaucoma detection from CFI is cup-to-disk ratio and Neuro-Retinal Rim (NRR). To calculate CDR, efficient segmentation of optic disk and optic cup are required. Once Optic Disk and Optic Cup are segmented, the ratio of vertical height of OC to OD is defined as cup-to-disk ratio. For a normal eye, the CDR value should be less than 0.3. In case of a glaucomatous eye, the cup progresses further into the neuro-retinal rim area resulting in the destruction of the nerve fiber layer. A healthy eye should satisfy Inferior, Superior, Nasal, Temporal (ISNT) rule i.e. the thickness of I≥S≥N≥T. Figure 2 shows CFI of glaucomatous eye, normal eye satisfying the ISNT rule, and glaucomatous eye not satisfying the ISNT rule. The CDR value hence increases in case of glaucomatous eye. So CDR value acts to differentiate between normal and glaucomatous eye.

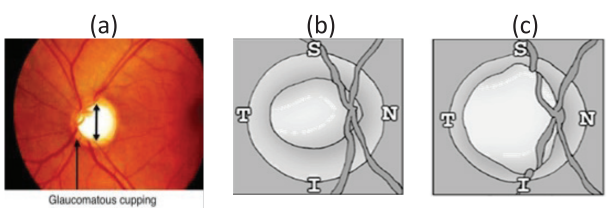

Figure 2. L to R: (a) CFI of a glaucomatous eye, (b) Normal eye satisfying ISNT rule, (c) Glaucomatous eye not satisfying ISNT rule.

Most of the present works have used either RGB based analysis or HSV based analysis for extracting Optic Disk and Optic Cup to calculate CDR[3-14]. In[7] the authors proposed CDR and ISNT rule based automatic glaucoma detection. For CDR calculation, Mean Threshold Morphological method is used. And to validate ISNT rule, logical AND operation is performed on the resultant images of optic disk and optic cup. The proposed method achieved an average accuracy of 97.5%. In [8], the authors proposed super pixels clustering, Simple Linear Iterative Clustering (SLIC) algorithm to calculate the CDR value. The proposed method extracted features from super pixels and utilized neural network classifiers to estimate optic disk and optic cup boundary. The sensitivity and specificity achieved by the proposed method is 92.3% and 88% respectively. In[9], the authors used Pearson-R Correlation Filter to segment Optic Disk and Optic Cup followed by the CDR calculation. The NRR thickness is calculated from the segmented OD and OC by using Euclidean distance measurement technique. The overall efficiency by proposed technique is found to be 97%. In[10], proposed Optic Disk localization by Hough transform. The success rate was 94.7% on DRIVE dataset and 90.9% on STARE dataset. In[13], proposed a method to extract Optic Cup from a manually selected set of pixels belonging to cup region. An ellipse is fitting method is adapted to this set of pixels to estimate the cup boundary. Cup boundary obtained via ellipse fitting yields only coarse cup boundary. Furthermore, fixed thresholding is also not adequate to handle large intensity variations within the Optic Cup region.In[14], the author extracted Optic Disk boundary using region-based statistics and Optic Cup boundary based on the appearance of pallor in Lab color space and the expected cup symmetry. A mean error 0.030 for normal and 0.121 for glaucomatous images is observed in the estimation of cup-to-disk ratio.

The problem with the mentioned literature is that either RGB based analysis or HSV based analysis has been done for extracting Optic Disk and Optic Cup. The problem with the RGB is that extreme amount of color variation is observed across all the three channels in the retinal image. The problem with the HSV image is that even though it offers much more homogenous areas in the retinal image, the edges are blurred between the cup, disk and the rest of the retinal image. LAB and YCbCr are other two popular transformed images which have been used by different past works for OD and OC area extraction. However intensity variation in LAB image is extremely low, where as the difference between different color channels is extremely low in YCbCr images. We find that instead of transforming the image to a different color mode, if we combine different color channels of RGB and LAB then the drawback of RGB, HSV and LAB color space can be overcome. This finding along with the ISNT rule is implemented as a proposed work which is elaborated in detail in the next section.

Some of the techniques like hough transform, elliptical transform proposed in the literature[10-13] fail to extract the exact Optic Disk and Optic Cup boundary even though they are elliptical in shape as there are extreme variations at the Optic Disk and Optic Cup boundaries. The proposed work also overcomes the limitation of some of the present system which assumes the Optic Disk and Optic Cup to be circular or near-circular.

2. Methodology

The calculation of CDR value requires Optic Disk and Optic Cup extraction from CFI. The Optic Disk and Optic Cup are extracted by a novel method of combining different color channels of RGB and LAB image followed by thresholding. Neuro-retinal rim area is the area between the OD and OC. Next, we find the cup progression in the NRR area in inferior, superior, nasal, and temporal area to verify the ISNT rule. The block diagram of the proposed work is depicted in Figure 3.

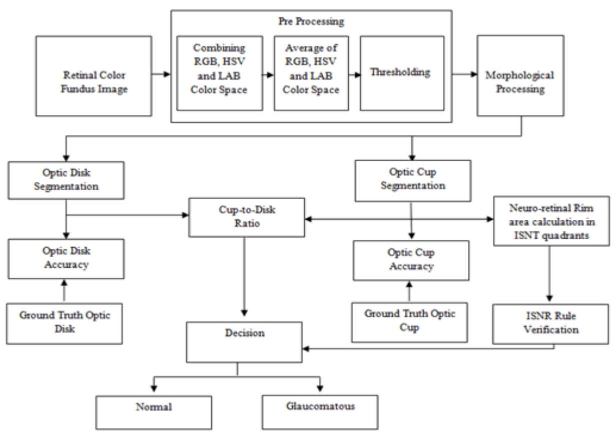

Figure 3. CDR calculation/ISNT rule.

2.1 Preprocessing

As our objective is morphology based Optic Disk and Optic Cup detection, we have adopted spatial domain preprocessing technique by combining different color channels of RGB, HSV and LAB. The proposed system first transforms the RGB image into a LAB color space. This is followed by taking the average of RGB and LAB color space. This results in extremely bright Optic Disk area. Experimental studies revealed that by adopting this technique, the Optic Disk area invariably appears at the highest possible color zone as depicted in Figure 4. Therefore instead of any kind of adaptive thresholding, we can directly threshold the Optic Disk area with the maximum intensity value.

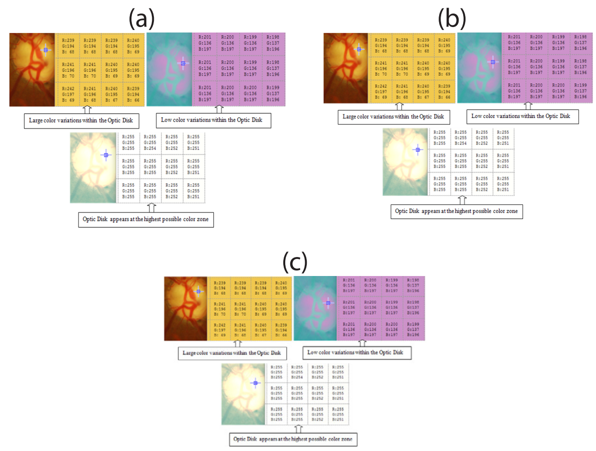

Figure 4. L to R: (a) Original RGB image, (b) LAB image, (c) RGB image combined with LAB image.

2.2 Morphological Processing

Preprocessing returns a binary image which would be having many redundancies and traces of binary noise. The noise is filtered using morphological operations. We have adopted morphological erosion followed by morphological dilation to first eliminate pixel noise followed by dilating the area or closing the area in order to compensate for the loss of data in the actual image.

2.3 Neuroretinal Rim Extraction and ISNT Rule Verification

Once the Optic Disk and Optic Cup is segmented, unlike the present system which uses only CDR as a measure to detect glaucoma, we propose a novel ISNT rule based glaucoma detection. The cup progression in the four regions of Neuroretinal Rim i.e. Inferior, Superior, Nasal, and Temporal is calculated and verified against the ISNT rule.

2.4 Decision

Unsupervised techniques are extremely popular for cases like image segmentation where the speed of the segmentation is of extreme importance. We have adopted unsupervised decision technique over here. We have adopted 92% of the maxima of the combined color channel image. Once the Optic Disk area is segmented, the proposed technique marks the Optic Disk boundary with Prewitt operator. This overcomes the method of current systems that assumes the OD and OC as elliptical (or circular) by offering an Optic Disk boundary tracing which is accurate to the shape of the exact Optic Disk boundary. Once the OD is extracted, we extract the LAB color space image within the Optic Disk area and transform it with the red channel of the RGB image. This results in precise Optic Cup area detection.

The segmented OD and OC by the proposed methodology are verified against the ground truth OD and OC by superimposing the segmented OD, OC with ground truth OD, and OC respectively. The OD, OC accuracy is then calculated by the percentage of overlap between the segmented and ground truth OD, and OC respectively.

Current state of art offers various techniques for Optic Disk and Optic Cup extraction, but a thorough review of the past literature reveals that most of the techniques offer OD and OC area detection with a maximum accuracy of 96%. As CDR value is extremely sensitive, 1% deviation in the detection of OD and OC area may result in tremendous amount of error in glaucoma detection. The proposed work overcomes the problem of low accuracy of Optic Disk and Optic Cup detection. Experimental results show that the overall efficiency of the proposed system is more than 97%.

Based on the CDR value and ISNT rule, the proposed methodology evaluates the image to be glaucomatous or normal.

3. Dataset for Glaucoma Evaluation

Dataset plays a crucial role in determining the effectiveness and validating the accuracy of automated glaucoma detection system. The reference dataset DRISHTI-GS1 provided by Medical Image Processing (MIP) group, IIIT Hyderabad is used for evaluating our proposed work[15]. DRISHTI-GS1database consists of 50 training and 51 testing images. Manual segmentations were collected for both Optic Disk and Optic Cup from four different glaucoma experts and were marked with a dedicated marking tool. In addition to this, diagnostic opinion for each image being normal or glaucomatous was obtained from four glaucoma experts and a gold standard was derived based on the majority opinion (i.e. 3 out of the 4 expert's opinion).

Figure 5 and 6 demonstrates the results of our proposed methodology when applied to a sample CFI of DRISHTI-GS1database.

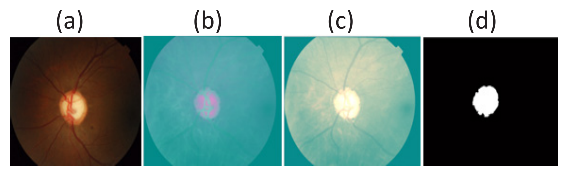

Figure 5. L to R: (a) RGB image (b) LAB (c) Combined image (c) Grey scale thresholded image.

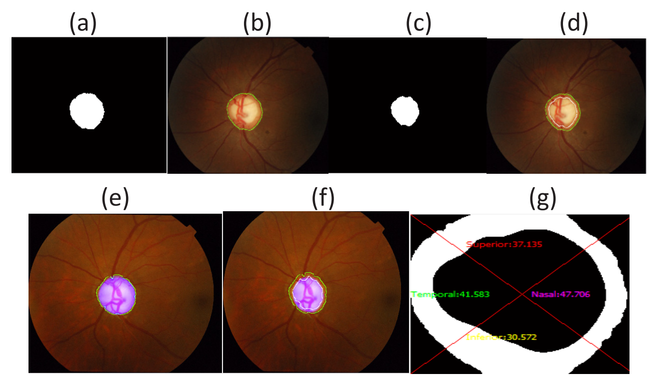

Figure 6. L to R: (a) Extracted Optic Disk, (b) Extracted OD marked on original RGB image, (c) Extracted Optic Cup, (d) Extracted OD and OC marked on original RGB image, (e) Extracted OD superimposed on glaucoma expert marked OD for Optic Disk accuracy, (f) Extracted OC superimposed on glaucoma expert marked OC for Optic Cup accuracy, (g) Optic Cup progression in NRR area (ISNT rule)

4. Performance Analysis

As the objective is to detect glaucoma from CFI, we opt for accuracy as the performance metric. DRISHTI-GS1dataset comes with a glaucoma expert marked truth images for both Optic Disk and Optic Cup areas. Both the Optic Disk and Optic Cup area detected by the proposed system is compared with the glaucoma expert marked OD and OC respectively and accuracy is measured by the percentage of overlap of detected OD and OC with that of glaucoma expert markings. The computed CDR by the proposed method is also compared against the glaucoma expert's value and the CDR accuracy is measured.

5. Experimental Results

We tested our proposed methodology against DRISHTI-GS 1 dataset. The proposed methodology's Optic disk segmentation accuracy is more than

99% and Optic Cup segmentation is more than 97%. The OD and OC segmentation is followed by the calculation of cup-to-disk ratio. The average CDR accuracy is more than 96% in comparison to the average computed value of CDR given by the 4-glacuoma experts. The OD and OC accuracy for sample images of 10 are shown in Table 1 and glaucoma detection based on CDR and ISNT rule verification is depicted in Table 2.

Table 1. Optic disk, optic cup and CDR accuracy.

Image No.	Proposed System		Proposed method CDR	Actual CDR	CDR Accuracy (In %)
	Disk Accuracy (In %)	Cup Accuracy (In %)			
drishtiGS_010	99.79	95.59	0.85	0.89	95.50
drishtiGS_012	99.90	95.25	0.85	0.87	97.70
drishtiGS_024	99.70	100	0.73	0.74	98.64
drishtiGS_026	99.34	95.26	0.83	0.88	94.31
drishtiGS_036	99.63	97.30	0.70	0.74	94.59
drishtiGS_058	99.95	95.40	0.79	0.84	94.04
drishtiGS_063	99.88	99.62	0.75	0.77	97.40
drishtiGS_064	99.71	98.71	0.78	0.82	95.12
drishtiGS_068	98.81	95.00	0.74	0.78	94.87
drishtiGS_069	99.55	98.65	0.77	0.78	98.71

Table 2. Glaucoma detection based on CDR value and ISNT rule.

Image No.	CDR Value	ISNT Rule Satisfied	Glaucoma Detected
drishtiGS_010	0.85	No	Yes
drishtiGS_012	0.85	No	Yes
drishtiGS_024	0.73	No	Yes
drishtiGS_026	0.83	No	Yes
drishtiGS_036	0.70	No	Yes
drishtiGS_058	0.79	No	Yes
drishtiGS_063	0.75	No	Yes
drishtiGS_064	0.78	No	Yes
drishtiGS_068	0.74	No	Yes
drishtiGS_069	0.77	No	Yes

6. Conclusion

Various past works have proposed efficient technique towards automated glaucoma detection system. These techniques includes adapting various color channels including RGB, HSV, and LAB color space for the segmentation of Optic Disk and Optic Cup. However study shows that they fail to provide a good accuracy due to inherent limitation of the corresponding color channel. Therefore in this work we have combined color channels (RGB, LAB) for the segmentation of Optic Disk and Optic Cup and the accuracy is found to be more than 97%. Accurate Optic Disk and Optic Cup segmentation results in efficient CDR value calculation. Also unlike the present system which uses only CDR as a measure to detect glaucoma, we proposed a novel CDR and ISNT rule based glaucoma detection.

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