International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-4 Issue-6, August 2015

An Automated System for Glaucoma Diagnosis

Saranya C.G., Lizy Abraham

Abstract*— Glaucoma is one among the major eye diseases which, if not treated, can lead to permanent blindness. Diagnosis of glaucoma in early stages plays a key role in preventing vision loss. The optic cup-to-disc ratio (CDR) in retinal fundus images is one of the principle physiological characteristics in the diagnosis of glaucoma. Currently, CDR is computed manually by specially trained clinician which is a time consuming and resource intensive process. This drew the attention of researchers in developing an automated system to aid ophthalmologists in glaucoma diagnosis. A new method for glaucoma screening based on CDR measurement is presented and discussed here. Active contour is used to find optic disc boundary and there by optic disc diameter is computed. Blue channel intensity profile is plotted to calculate optic cup diameter. Higher value of CDR indicates glaucoma whereas normal eyes have small CDR value. The method was tested on publicly available database HRF and has attained better results than conventional approaches.

Index Terms*— Active contour, Cup-to-disc ratio (CDR) Glaucoma, Optic disc.

I. INTRODUCTION

According to the surveys carried out glaucoma is found to be the second most cause for vision loss worldwide. World Health Organisation (WHO) has estimated that about 4.5 million persons globally are blind due to glaucoma [1]. Also H.A. Quigley and A.T. Broman have revealed that this number will rise to 11.2 million by the year 2020 in their journal [2]. Thus diagnosis of glaucoma in earlier stage itself is of great importance to prevent vision loss.

Glaucoma is a condition aroused due to increase in fluid pressure within the eye. This increased pressure eventually leads to larger cupping of optic nerve and one can finally lose their vision due to severe nerve damage. Therefore the value of cup-to-disc ratio (CDR) gives an idea about the size of the cup compared to that of the disc and thus CDR value is used for glaucoma diagnosis. It can take values within the range 0.1 to 1.0. Higher value of CDR means condition is more critical. If the value of CDR is greater than or equal to 0.95 then it is a case where vision is completely lost and cannot be restored by any means.

This paper proposes an automated system for the diagnosis of glaucoma based on CDR. The system is basically an image processing system as the diagnosis is carried out on retinal fundus images. Retinal fundus images are photographs of inner layer of eye (retina) which include optic nerve head (optic disc), macula etc.

There are two possible way for diagnosis of eye diseases, either using anatomical feature extraction or textural feature extraction. Here anatomical feature extraction technique is used and anatomical structure extracted is the optic disc. Therefore the first step is finding the location of the optic disc and then it is extracted from the retinal fundus image. The remaining processes are carried out on extracted optic disc, thus optic disc diameter as well as optic cup diameter is acquired. Using this, CDR is calculated and finally glaucoma is diagnosed. To develop such a system, thorough understanding about existing methods and existing techniques is mandatory and section II gives an idea about related works done in this area.

II. RELATED WORKS

The glaucoma diagnosis has different stages like optic disc localization, boundary detection. Many studies are carried out in each these stages. The optic nerve head localization can be done based on blood vessel extraction and convergence [3]. Multiple vessel segmentation of same image and fuzzy convergence is used to determine the origin of blood vessel network which itself is the optic nerve head where as in [4] they focus on segmentation of optic disc and optic cup than localization. Optic disc and cup segmentation for glaucoma screening is done using superpixel classification. Histograms and center surround statistics are used to classify each superpixel as disc or non-disc, thus optic disc is segmented and this segmentation is self-assessed. Then for optic cup segmentation along with histograms and center surround statistics, the location information is also included into the feature space to improve the performance.

A mixed model-based [5] approach can also be used for segmentation. Similar to above mentioned work here also focus is on segmentation, especially optic cup. Gaussian probabilistic mixture model is used for optic cup segmentation which exploits the advantages of the ARGALI level set segmentation and regulates the cup boundary in the temporal zone. A regional propagation approach based on retinal structure priors can be used to localize the optic cup in 2D fundus images [6]. In this work, localization of the optic cup in a given disc image is done using segmentation methods i.e. the input disc image is segmented into superpixels and superpixels corresponding to blood vessels are removed. Then superpixels are labeled as the cup or rim based on structure priors and these labels are propagated to the remaining superpixels. Thus the superpixel labels are refined and then finally cup location is determined by ellipse fitting.

Manuscript published on 30 August 2015.
***** Correspondence Author (s)
Saranya C.G., Department of Electronics and Communication, LBS Institute of Science and Technology for Women, Thiruvananthapuram, India.
Dr. Lizy Abraham, Department of Electronics and Communication, LBS Institute of Science and Technology for Women, Thiruvananthapuram, India.

Another technique used is a depth discontinuity-based approach to estimate the cup boundary [7]. The work focuses on cup boundary rather than cup region. In this work, sequentially acquired set of images are related via a relative motion model and the depth discontinuity at the cup boundary is determined from cues such as motion boundary and partial occlusion. Then the information encoded by these cues is used to approximate the cup boundary with a set of best-fitting circles and finally the boundary is found by considering points on these circles at different sectors using a confidence measure.

III. PROPOSED METHOD

After the systematic study of existing methods and their drawbacks, a novel method for optic disc extraction is proposed. Thereby an automated system for the diagnosis of glaucoma based on CDR is developed. The flow chart of the proposed system is shown below. The input to the system is retinal fundus image in RGB format.

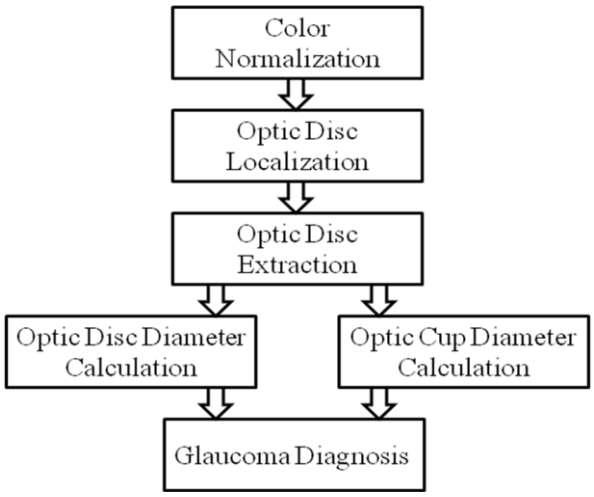
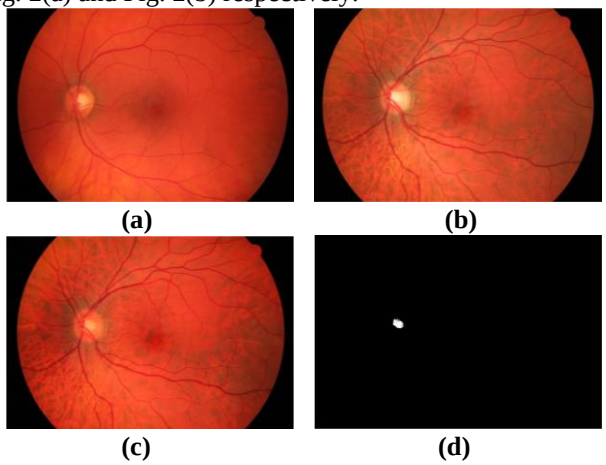


Fig. 1 Flow chart of the proposed system

A. Color Normalization

As our optic disc localization is based on intensity profile, the histogram of all input images must be matched to the histogram of a reference image by which the intensity distributions of input images can be redefined as required for localization stage. The reference and input image is shown in Fig. 2(a) and Fig. 2(b) respectively.



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

Fig. 2 (a) Reference image (b) Input image (c) Colour normalized image (d) Optic disc localized image

For this, first find the histogram of the input as well as reference image and then input images histogram is given desired shape as that of reference by histogram matching (specification) [8] and Fig. 2(c) shows the obtained output. This is done separately for each colour channel as shown in Fig.3.

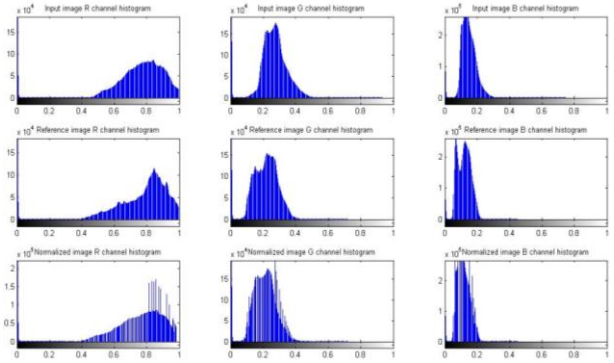


Fig. 3 Histogram matching for each colour channel

B. Optic Disc Localization

After colour normalization we are done with image enhancement, now the position of optic disc in given input image is to be found for the extraction of the same. The blue channel can be used for localization. This is because the blue channel intensity profile has peak value at optic disc unlike other two channels. In the case of other two channels there is possibility for more than one peak which may lead to ambiguity. The blue component of the RGB image can be considered as a gray scale image and it is converted to binary image by thresholding. The threshold for this conversion is set to a value greater than the median of blue channel intensities. In the binary image obtained after thresholding (Fig. 2(d)), the white pixels represent the possible centroid of optic disc.

C. Optic Disc Extraction

Using the co-ordinate information obtained in the above stage the optic disc is extracted out from the whole retinal fundus image so that further processing will be carried out in the region of interest alone and thus amount of data to be handled and number of computation required can be reduced drastically. In the extraction stage a window is defined based on optic disc centroid and size, which varies depending on the database we use. The largest optic disc in the dataset gives an idea about how large the cropping window should be, in order to accommodate each optic disc in that entire dataset. The localization stage gives a set of white pixel, where the possible centroid of optic disc can be and (C_X, C_Y) i.e. the actual centroid is calculated as follows:

Let (x_i, y_i) be the co-ordinate of i^{th} white pixel and X, Y are two column matrix of size n, where n is the number of white pixel.

$$X = \{x_i, \text{ for } i=1, 2, \ldots n\} \quad (1)$$
$$Y = \{y_i, \text{ for } i=1, 2, \ldots n\} \quad (2)$$

$$C_X = \text{mean } (X) \quad (3)$$
$$C_Y = \text{mean } (Y) \quad (4)$$

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Using the calculated centroid the cropping window is positioned to crop out the optic disc and top left corner co-ordinate of window must be placed at (C_X-W/2, C_Y-W/2) for the extraction, where W is size of window (i.e. W x W). Fig. 4(a) shows the output after extraction.

D. Optic Disc Diameter Calculation

Optic disc has been extracted but still we have not found its boundary. The boundary has to be estimated in order to calculate the disc diameter. Active contour technique is used here on the sharpened image for optic disc boundary detection. Active contour technique makes use of Chan-Vese segmentation algorithm [9] and need an initial mask as shown in Fig. 4(b), which is defined manually. Using this mask, optic disc boundary is estimate iteratively.

In Chan-Vese model u is defined as

$$u(x) = \begin{cases} c_1 \text{ where x is inside C} \\ c_2 \text{ where x is outside C} \end{cases} \quad (5)$$

where C is the boundary of a closed set and c_1, c_2 are the values of u respectively inside and outside of C. Here we have to find that value of u that approximates f in the best way from all possible values of u, for that we use the equation given below.

$$\arg\min_{(c_1, c_2, C)} (\mu \text{ Length}(C) + \nu \text{ Area}(\text{inside}(C)) + \lambda_1 \int_{\text{inside C}} |f(x) - c1|^2 \, dx + \lambda_2 \int_{\text{outside C}} |f(x) - c2|^2 \, dx) \quad (6)$$

In the equation, the first term penalizes the length and thereby controls the regularity where as the second term penalizes the enclosed area of C to control its size. The third and fourth terms represents the penalty paid for discrepancy between the piecewise constant model u and the input image f. Thus segmentation is obtained as the best two-phase piecewise constant approximation u of the image f by finding a local minimizer of this problem and the output obtained is a binary image as in Fig. 4(c). By mapping this image to original image area outside optic disc is removed. To get a clear idea about this mapping look at the Fig. 4(d).

Now simply by means of intensity plot diameter can be calculated. The intensity is plotted in four directions to improve accuracy i.e. horizontal, vertical and along two diagonals. Then the lower extreme and upper extreme of intensity plots are to be found and their difference gives the disc diameter. If we consider our image to be a 2-D matrix of size N x N, then lower extreme is value of x for which intensity is non-zero, as x varies from 1 to N and upper extreme is value of x for which intensity is non-zero, as x varies from N to 1. This is in the case of horizontal plot. Similarly we can find the extremes in other directions too and the diameter is the difference between lower and upper extreme in each case. Then the mean of diameter in four directions gives approximate value of disc diameter. But among these only those diameter greater than 60% of image size (image obtained after boundary detection) are considered to avoid error due to the presence of blood vessels.

E. Optic Cup Diameter Calculation

Now the focus is on optic cup and it should be extracted from the disc image. Blue channel intensity profile of optic disc region is similar to Gaussian distribution and it can be used for optic cup boundary detection [10]. But detection of entire cup boundary is not required as glaucomatous cupping deforms only in vertical direction and thus we are interested in vertical diameter alone. Moreover cup boundary detection can only make the process complex and time consuming. Therefore intensity profile in vertical direction alone is considered and then threshold is applied on the profile to obtain the cup diameter.

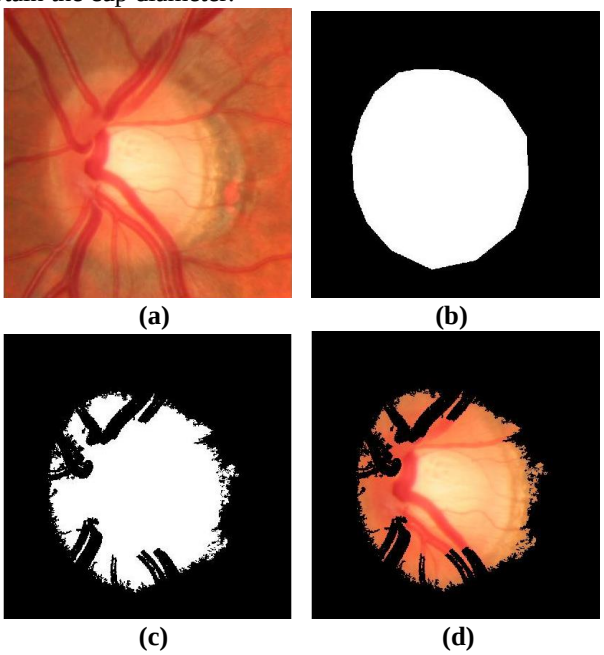

Fig. 4 (a) Optic disc extracted image (b) Initial mask for active contour (c) Segmented image obtained using active contour (d) Optic disc boundary detected image

F. Glaucoma Diagnosis

We have already calculated optic disc diameter as well as optic cup diameter; therefore CDR can be easily calculated by taking the ratio of the two. Then based on this CDR value we classify the input image into three categories and for that we need to set two thresholds. These thresholds are set with the help of an ophthalmologist. First category is healthy optic disc with CDR less than 0.50, second category is optic disc with large cupping and further test is required to confirm whether it is healthy or not with CDR ranging from 0.50 to 0.60, third category is glaucomatous optic disc with CDR greater than 0.60. Thus the system helps in preliminary glaucoma diagnosis because field test and fluid pressure test is required in certain cases to confirm glaucoma.

IV. EXPERIMENTAL RESULTS

The proposed system for glaucoma diagnosis is tested on HRF images. Then the diagnosis result obtained for each input image is compared with that of an expert and those comparison results are analyzed to evaluate the performance of the system. The parameters used for this analysis are sensitivity, specificity and accuracy. They are mathematically expressed as:

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$$\text{Sensitivity} = \frac{TP}{(TP + FN)} \quad (7)$$

$$\text{Specificity} = \frac{TN}{(TN + FP)} \quad (8)$$

$$\text{Accuracy} = \frac{(TP + TN)}{(TP + FN + TN + FP)} \quad (9)$$

The parameters TP, TN, FN and FP are defined based on the hypothesis we are taking. If we take presence of glaucoma as positive condition and absence of glaucoma (i.e. healthy condition) as negative condition, then true positive (TP) is the case where glaucomatous input is detected as glaucomatous, true negative (TN) is the case where healthy input is detected as healthy, false positive (FP) is the case where healthy input is detected as glaucomatous and false negative (FN) is the case where glaucomatous input is detected as healthy. Therefore sensitivity can be defined as the measure of ability of the system to classify glaucomatous input as glaucomatous. Then specificity is the measure of ability of the system to classify healthy input as healthy and accuracy measures the ability of the system to classify glaucomatous as glaucomatous and healthy as healthy. Therefore high accuracy means the system classifies well with minimum number of misses and false alarms. Also for better diagnosis the value of sensitivity and specificity must be high. Sensitivity and specificity are also referred to as True Positive Rate (TPR) and True Negative Rate (TNR), respectively. To evaluate the proposed system performance we calculated sensitivity, specificity and accuracy of the system. The result shows that the system is 100% sensitive and moreover specificity and accuracy values are found to be satisfactory. Specificity and accuracy of the system is 91% and 94% respectively, when tested on HRF database [11].

V. Conclusion

This paper presented a new method for glaucoma diagnosis based on CDR calculation. The focus was on the successful localization of optic disc to identify the disc ROI and calculate the disc and cup diameters. Detection of disc and cup from the ROI image is more efficient than running the algorithm over entire image. Disc boundary is obtained using active contour. Based on the value of CDR, glaucoma screening is done. The method was implemented on MATLAB R2013a and was tested on retinal fundus images from HRF database. It required approximately 18 seconds for diagnosing single image, where the time taken to define initial mask for active contour is excluded. The false alarm rate is traded off so as to keep the miss rate minimum. The proposed method showed high sensitivity and the results are encouraging to extend it for further evaluation to be able to integrate to an early glaucoma screening system.

Acknowledgment

The authors would like to thank Dr. K. Mahadevan for his valuable suggestions and help throughout this work. He is one of the reputed Ophthalmologist/Eye Surgeon in Trivandrum and he is currently practising at Vasan Eye Care Hospital, Pattom, and Trivandrum.

References

1. World Health Organization, VISION2020: The Right to Sight, Global Initiative for the Elimination of Avoidable Blindness: Action Plan 2006 –2011, World Health Organization, Geneva, Switzerland; 2007; page no.1–2.
2. Quigley H.A., Broman A.T., The number of people with glaucoma worldwide in 2010 and 2020. Br J Ophthalmol. 2006; 90:262-267. Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1856963.
3. Adam Hoover and Michael Goldbaum, "Locating the Optic Nerve in a Retinal Image Using the Fuzzy Convergence of the Blood Vessels" IEEE Transactions on Medical Imaging, Vol. 22, No. 8, August 2003.
4. Jun Cheng, Jiang Liu, Yanwu Xu, Fengshou Yin, Damon Wing Kee Wong, Ngan-Meng Tan, Dacheng Tao, Ching-Yu Cheng, Tin Aung, and Tien Yin Wong, "Superpixel Classification Based Optic Disc and Optic Cup Segmentation for Glaucoma Screening", IEEE Transactions on Medical Imaging, Vol. 32, No. 6, June 2013.
5. N.M. Tan, J. Liu, D.W.K. Wong, F. Yin, J.H. Lim, and T.Y. Wong, "Mixture Model-based Approach for Optic Cup Segmentation", 32nd Annual International Conference of the IEEE EMBS.
6. Yanwu Xu, Jiang Liu, Jun Cheng, Fengshou Yin, Ngan Meng Tan, Damon Wing Kee Wong, Mani Baskaran, Ching Yu Cheng and Tien Yin Wong, "Efficient Optic Cup Localization Using Regional Propagation Based on Retinal Structure Priors", 34th Annual International Conference of the IEEE EMBS, San Diego, California USA, 28 August - 1 September, 2012.
7. Gopal Datt Joshi, Jayanthi Sivaswamy, S. R. Krishnadas, "Depth Discontinuity-Based Cup Segmentation from Multiview Color Retinal Images", IEEE Transactions on Biomedical Engineering, Vol. 59, No. 6, June 2012.
8. R. C. Gonzales and R. E. Woods, *Digital Image Processing*, 2002 Prentice Hall.
9. T. Chan and L. Vese, Active contours without edges, IEEE transactions on image processing 10 (2) (2001), pp. 266-277.
10. Yuji Hatanaka, Atsushi Noudo, Chisako Muramatsu, Akira Sawada, Takeshi Hara, Tetsuya Yamamoto, and Hiroshi Fujita, "Automatic Measurement of Cup to Disc Ratio Based on Line Profile Analysis in Retinal Images", 33rd Annual International Conference of the IEEE EMBS Boston, Massachusetts USA, August 30 - September 3, 2011.
11. High-Resolution Fundus (HRF) Image Database. Available: https://www5.cs.fau.de/research/data/fundus-images.

Saranya C.G. is currently pursuing her M.Tech. Degree in Signal Processing with the Department of Electronics and Communication Engineering, LBS Institute of Technology for Women, Poojappura, Trivandrum, Kerala. She received her B.Tech degree in Applied Electronics and Instrumentation from Kerala University, in 2013.

Dr. Lizy Abraham completed her Ph.D in Satellite Images, presently working as an Assistant Professor, LBS Institute of Technology for Women, Trivandrum, Kerala, India. Her research works include extraction of structural features such as roads, buildings and bridges of urban and non-urban areas from satellite images using Image - Signal processing tools and Soft Computing methods. She has published one book in this area and another book on LabVIEW for Signal Processing and Control System Labs. Her current research interests include sensor networks, biomedical imaging and weather forecasting. She has completed a funded research project in sensor networks. She has presented and published several papers in International Conferences and Journals.

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