Knowledge Based Framework for Localization of Retinal Landmarks from Diabetic Retinopathy (*DR*) Images

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Abstract **-We propose an algorithm for the detection of retinal landmarks (optic nerve head or optic disc, macula, and vasculature) based on optic cup location and anatomical structural details from diabetic retinopathy (DR) images of both left and right eye. Our algorithm uses color fundus images obtained from mydriatic camera. The algorithm proceeds through four main steps**
1. Color image pre-processing- to enhance and remove noise from the image. 2. Detection of optic nerve head -The optic nerve head is located using a fact that the optic cup is the brightest region in the optic nerve head. At the same time exudates (DR lesion) which appear in same gray level as optic nerve head are suppressed since we only concentrate on optic cup and optic nerve head. So by calculating the mean value of the intensities of 50x50 subimages (50x50 is approximate area of optic cup) throughout the image and then selecting that 50x50 sub image with the highest mean value, locates optic cup in the image. Using this, optic nerve head is located by increasing the area of interest around the optic cup. Since we detect optic cup first, which is embedded in optic nerve head there will not be any false detection of optic nerve head when size and shape of the exudates (DR lesion) are same as that of optic nerve head 3.Detection of macula-It is located at a distance of approximately twice the diameter of the optic nerve head just below the horizontal axis of the optic nerve head.
4. Detection of vasculature-We have used logical AND operation on two images, one being a thresholded image and another being an edge detected image. The thrsholding is done on an adaptive histogram equalized image. Edge detection is done using canny edge detector. Proposed algorithm has been tested on both normal and DR images. Detected optic disc area is validated by comparing it with expert ophthalmologists' hand-drawn ground-truths. The quantitative performance is evaluated by calculating sensitivity, specificity and predictive value. Overall sensitivity (Se), specificity (Sp) and predictive value (PV) obtained in detecting optic nerve head from normal images and from abnormal images are 97.2%, 99.72%, and 88.75% and 93.93%, 99.72%, and 84.18% respectively.

Keywords- Diabetic retinopathy; retina; optic nerve head; blood vessels; macula

I. INTRODUCTION

The Diabetic Retinopathy (DR) is a complication of diabetes that is caused by changes in the blood vessels of retina. The symptoms can distort or blur the patient's vision and are the main causes of blindness. The identification of fundal landmark features such as optic nerve head, macula and the retinal vessels as reference co-ordinates, is a prerequisite before systems can achieve more complex tasks of identifying pathological entities from DR images. Position of optic nerve head with respect to macula is used to differentiate left eye and right eye. When optic nerve head is swollen and lesions particularly exudates, are very near to optic nerve head and if the size and brightness of exudates are same as that of optic nerve head in that case there is possibility of false detection of optic disc. The location of optic nerve head is important in retinal image analysis, to locate anatomical components in retinal images, for vessel tracking, as a reference length for measuring distances in the retinal images and for registering changes within the optic disc region due to disease. Locating macula is important in order to detect maculopathy when DR lesions overlap the macula. Care has to be taken while giving laser treatment in treating DR since macula is responsible for central vision.

In earlier research work optic nerve head is detected based on brightness, shape and size. These methods work well when the area of the exudates is not large and optic nerve head is round in shape, normal in size. Hence, a method based on lone features such as shape, brightness and size shows a large variance and makes this detection erratic, particularly in the presence of retinal disease.

A. Features of Optic Nerve Head and Optic Cup

Normal structures of the retina are optic nerve head, macula, and blood vessels. The small area of the retina where optic nerve leaves the eye is optic nerve head. This is the bright yellow part in the normal fundus image that can be seen as round or vertically oval. The optic cup which is embedded in optic nerve head is the brightest, cup-like area in the optic nerve head. About 0.5cm to the nasal side of macula all nerve fibers of the retina converge to form the optic nerve.

B. Features of Macula

Macula is an oval shaped highly pigmented, located roughly in the center of the retina, temporal to the optic nerve. It is a small and highly sensitive part of the retina responsible for detailed central vision. The fovea is at the centre of the macula.

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C. Features of Blood vessels

An important aspect of DR is the microvascular changes that cause detectable changes in the appearance of the retinal blood vessel. In diabetic retinopathy, the fine vessels on the surface of the retina become damaged, a condition that can be treated by laser surgery. The blood vessels have lower reflectance compared to other retinal surfaces.

D. Features of Exudates

These are one of the main characteristics of DR and can vary in size from tiny specks to large patches. Hard exudates are bright yellow color with well defined margins. Weakening of retinal capillary walls and loss of pericyte support, give rise to microaneurysm formation. Serum lipoproteins leak from microaneurysms and are deposited as exudates. These intra retinal deposits are intimately associated with various retinal pathologies and detection of exudates is quite important for the early diagnosis of DR.

For example, Fig.1 (a) shows normal fundus image and Fig.1 (b) shows fundus image in DR exhibiting exudates.

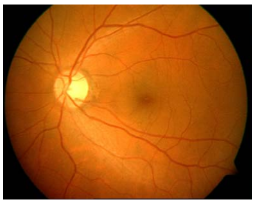

Figure 1. (a) Normal fundus image (left eye) (b) Abnormal Fundus image with exudates (right eye).

II. RELATED WORK

There are three approaches to detect the optic nerve head as follows:

- Geographic approach: This approach is mainly based on the information provided by the vessel structure.
- Model based approach: This approach is mainly based on model of geometrical directional pattern of the retinal vascular system, and implicitly embeds the information on the optic disc position as the point of convergence of all vessels.
- Image feature based approach: This approach is based on its specific round shape and relatively high brightness, as compared to the rest of the fundus image.

The features (shape, size, brightness) of the optic nerve head are useful for identification of optic nerve head in a normal fundus image. In most of the research works optic nerve head has been identified from the known features such as shape, brightness, size based on template matching, principle component analysis and thresholding methods.

Lalonde et al [1] localized the optic nerve head using template matching and pyramidal decomposition. Snake techniques was employed to extract optic nerve head boundary in work [2].Since templates are based on size ,shape and brightness, localizing optic nerve head is not possible in the presence of exudates having same features as optic nerve head particularly when optic disc is distorted in shape and size in the abnormal retina. In the work of Li and Chuttatape [3] [4], optic disc was located by principle component analysis (PCA) and its shape was detected by modified active counter shape model. Mira Park presented a method to outline the optic disc using thresholding and circle detection by Hough transform [5].

There are many previous works on extracting blood vessels. Tracking based method is used in [10]. Binary segmentation based on maximizing entropy is used in [11]. Giribabu used spatially weighted fuzzy c-means clustering algorithm to segment blood vessels [12].

III. MATERIAL

Fundus images used in this work are captured by a Sony mydriatic fundus camera, with a 50° field of view, at Minto Regional Eye Hospital, Bangalore. The images were stored in JPEG image format files (.jpg). The image size is 576 × 768 at 24 bits, true color images. We have used images of both right eye and left eye.

IV. PROPOSED METHOD

A. Image Preprocessing

Contrast of the color image is enhanced and then median filter which is a nonlinear filter is used to reduce ‘salt and pepper’ noise. A median filter is more effective than convolution when the goal is to simultaneously reduce noise and preserve edges. We choose only green component of the color image since in this channel all the features of the image are clear as compared to red and blue channel. Red channel is discarded because it tends to be saturated and has less contrast than green one while blue channel contains only noise. Then contrast-limited adaptive histogram equalization (CLAHE) is used to enhance contrast of small regions in the image. CLAHE operates on small regions in the image, called tiles, rather than the entire image. Each tile's contrast is enhanced, so that the histogram of the output region approximately matches the histogram specified by the 'Distribution' parameter. The neighboring tiles are then combined using bilinear interpolation to eliminate artificially induced boundaries. The contrast, especially in homogeneous areas, can be limited to avoid amplifying any noise that might be present in the image.

By selecting suitable threshold, histogram equalized image is thresholded so that only dark regions (including blood vessels) are visible. This threshold value is selected by trial and error method. Dilation operation is performed to achieve continuity in detected blood vessels. Edge detection is performed on the green component image using canny filter with suitable threshold. Dilation operation is performed to add pixels around the existing ones. Logical AND operation is performed on thresholded and canny edge detected images. Fig.2 shows procedure for detection of vasculature.

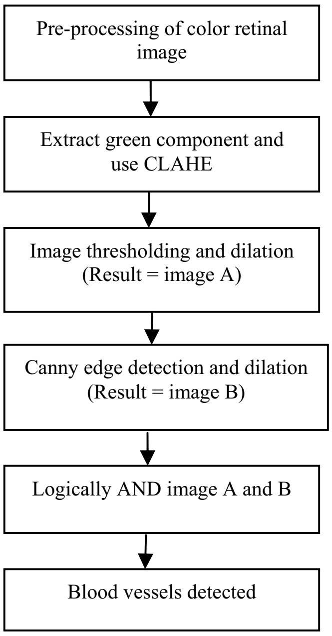

Figure 2. Procedure to detect vasculature.

B. *Detection of Optic Nerve Head And Macula*

For detecting optic nerve head we use green component of the image which is enhanced using CLAHE. A mask of size 50x50 is defined (50x50 is approximate area of optic cup).The mean values of the sub images under the mask are calculated and the coordinates of the sub image with maximum mean is stored. These coordinates give the position of optic cup, the brightest region in the optic nerve head. Using this knowledge the optic nerve head region is located by increasing the coordinates around optic cup for both left and right eye to obtain optic nerve head region. The end coordinates of this optic nerve head region (a rectangular region) are used to locate the macula.

Macula is segmented using the anatomical details, that the macula is situated at a distance of around twice the diameter of the optic nerve head and just below the horizontal axis of optic nerve head. Now the coordinates are shifted accordingly to get the macular region.

Fig.3shows procedures for detection of optic nerve head and macula.

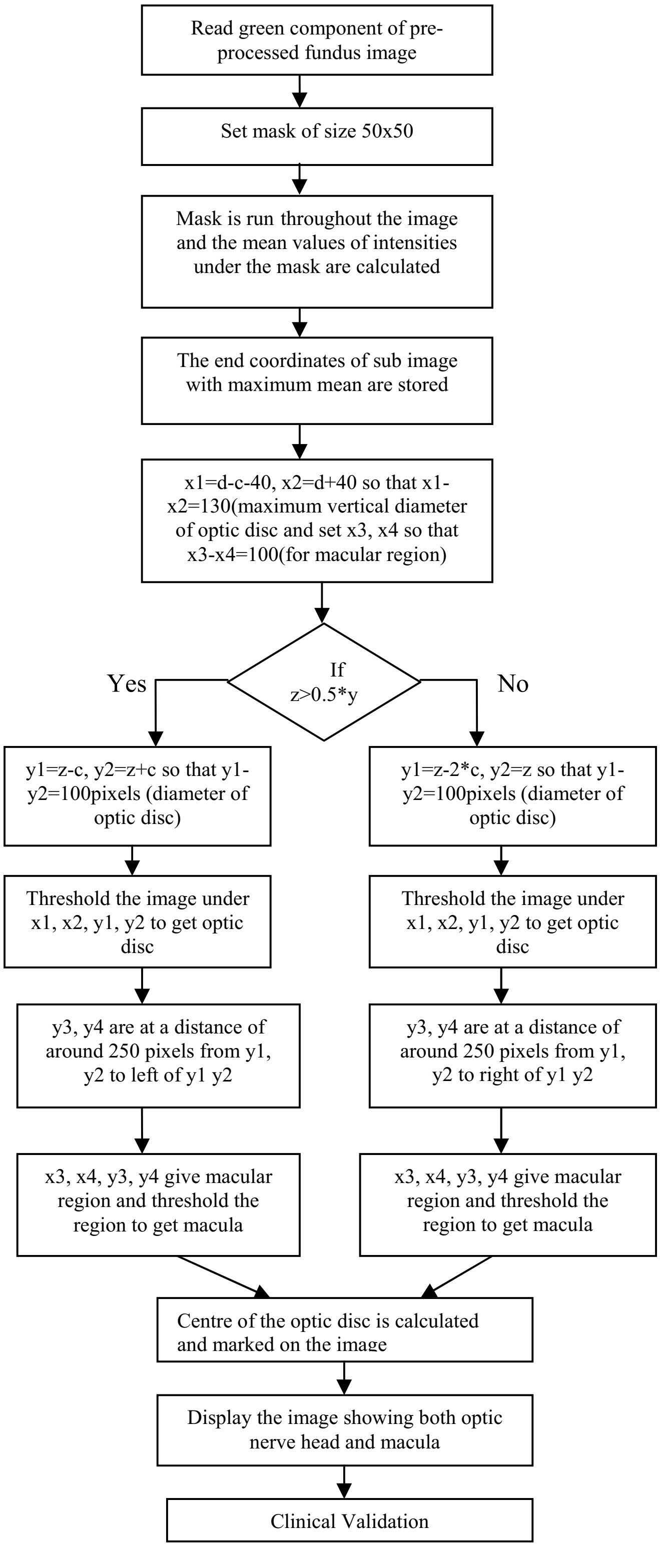

Figure 3. Procedure to detect optic nerve head and macula.

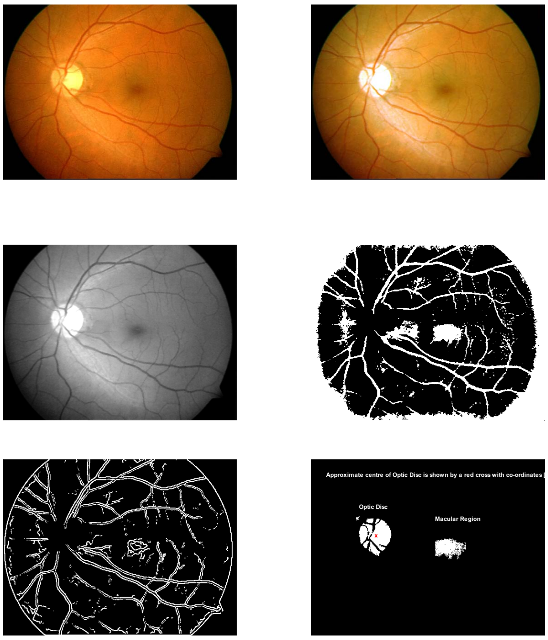

Figure 4. (a) Color fundus image(left eye) (b) Pre- processed color image (c) Green component of the image (d) Thresholded image (e)Canny edge detection and dilated image (f) Segmented optic nerve head and macula .

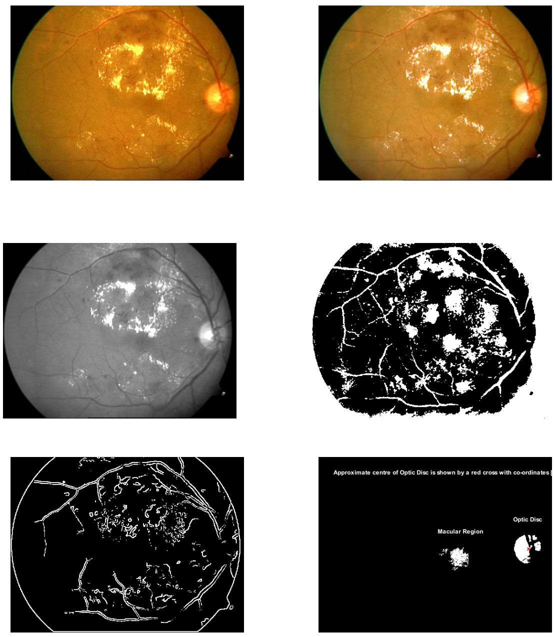

Figure 5. (a) Color fundus image in DR (right eye) (b) Pre- processed color image (c) Green component of the image (d) Thresholded image (e)Canny edge detection and dilated image (f) Segmented optic nerve head and macula

V. RESULTS

We have tested proposed algorithm on eight normal and nine abnormal fundus images using Matlab version 7.5. Fig 4 and Fig.5 show the results of the proposed algorithm for normal and abnormal fundus images. The performance of our algorithm is evaluated quantitatively by comparing the resulting extractions with ophthalmologists' hand-drawn ground-truth images pixel by pixel. In order to facilitate the expert to produce ground-truth images, at first draft of ground truth image was created by us. We have marked the optic nerve head using a photo manipulation program with one color. Then the first draft images were shown to expert with the original images. The ophthalmologist then made some changes by adding some missing pixels and/or removing some misunderstood pixels of optic nerve head region. Sensitivity (Se), Specificity (Sp) and predictive value (PV) are chosen as measurements of accuracy of the algorithm at the pixel level. This pixel based evaluation considers four values, namely true positive (TP), a number of optic nerve head pixels correctly detected, false positive (FP), a number of optic nerve head pixels which are detected wrongly as optic nerve head pixels, false negative (FN), a number of optic nerve head pixels that were not detected and true negative (TN), a number of optic nerve head pixels that were correctly identified as non optic nerve head pixels. From these quantities, the sensitivity, specificity, and predictive value (PV) are computed using equations (1), (2) and (3).

$$\text{Sensitivity} = TP / TP+FN \qquad (1)$$

$$\text{Specificity} = TN / TN+FP \qquad (2)$$

$$PV = TP / TP+FP \qquad (3)$$

TABLE I. PERFORMANCE OF THE PROPOSED METHOD ON DETECTING THE AREA (PIXELS) OF OPTIC NERVE HEAD FROM NORMAL FUNDUS IMAGES

Im	GT	D	TP	FP	FN	Se (%)	Sp (%)	PV (%)
D1	7253	7387	7120	267	133	98.16	99.93	96.36
D2	7960	9126	7896	1230	64	99.20	99.71	86.6
D3	6025	6604	5563	1041	462	92.33	99.75	84.23
D4	6271	8834	6071	2763	200	96.81	99.36	96.81
D5	5353	6763	5184	1579	169	96.93	99.63	77.22
D6	4624	4960	4545	415	79	98.29	99.88	91.63
D7	8667	9063	8569	494	98	98.86	99.88	95.54
D8	7595	9026	7369	1657	226	97.02	99.62	81.64
overall						97.2	99.72	88.75

TABLE II. PERFORMANCE OF THE PROPOSED METHOD ON DETECTING THE AREA (PIXELS) OF OPTIC NERVE HEAD FROM ABNORMAL FUNDUS IMAGES

Im	GT	D	TP	FP	FN	Se (%)	Sp (%)	PV (%)
D1	4831	5738	4671	1067	160	96.68	99.75	81.40
D2	7271	8971	6756	2215	515	92.91	99.88	75.30
D3	9078	9354	8507	847	571	93.71	99.80	90.90
D4	3960	4046	3941	105	19	99.52	99.97	97.40
D5	6388	7883	5186	2697	1202	81.18	99.38	65.78
D6	4205	4254	4055	199	150	96.43	99.95	95.32
D7	4962	5360	4604	756	358	92.78	99.82	85.89
D8	4595	5148	4236	912	359	92.18	99.79	82.28
D9	6153	7113	5933	1180	220	96.42	99.95	83.41
overall						93.93	99.72	84.18

GT-Ground truth pixels, D-Detected pixels, Se-Sensitivity, Sp-Specificity, PV-Predective value

PV is the probability that a pixel has been classified as optic nerve head pixel is really a part of optic disc [11].

After processing all 17 images, they were compared with the hand drawn ground-truth images. Table I and Table II show the quantitative result of our algorithm. For our data set the overall sensitivity, specificity and PV in detecting optic nerve head from normal images are obtained as 97.2%, 99.72%, and 88.75% respectively and for abnormal images overall sensitivity, specificity and PV in detecting optic nerve head from abnormal images are obtained as 93.93%, 99.72%, and 84.18% respectively

For images D2 and D5 in Table II, PV obtained is 75.30% and 65.78% respectively. This is because in this images optic nerve head edges are not sharp due to edema to the optic nerve head. Hence the boundaries of the ground truth optic nerve head and detected one could not be predicted very precisely.

VI. DISCUSSION

In this algorithm we have investigated and proposed a method based on anatomical structural details and retinal image information. This system intends to help the ophthalmologists not only in DR screening process but any other eye related abnormality which is based on retinal photography. It is not a final result application but it can be a preliminary diagnosis tool or a decision support system for ophthalmologists. Human ophthalmologists are still needed for the cases where detection results are not very obvious. This type of presentation will enable clinicians to identify retinal landmarks more quickly and will also help to take decision while treating the abnormality, particularly maculopathy.

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