Automatic localization of fovea in retinal images based on mathematical morphology and anatomic structures

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Abstract — Diabetic macular edema is one of the retinal abnormalities which affects the central vision of the person and causes total blindness in severe cases. Fovea (center of macula) localization is an important step in retinal image analysis especially for grading diabetic macular edema. This paper describes a method to automatically localize the fovea center in retinal fundus images. The method is mainly based on mathematical morphology along with the information of other anatomic structures such as blood vessel and optic disc. Initially, the vascular structure and optic disc center are extracted, and then the morphological operations are employed on the gray scale image of green channel for fovea candidates' selection. The candidates' satisfying area, density and distance criteria are considered for the final stage. In the final stage, the candidate having lesser vessel pixels was considered as fovea region. The proposed method was evaluated on the two publicly available DRIVE and STARE databases. The method was able to obtain 100% of fovea localization accuracy on DRIVE database with 2.88 seconds average computation time.

Keywords: Retinal image analysis, Fovea localization, Diabetic macular edema.

I. INTRODUCTION

The central portion of retina which is usually darkest in digital fundus image and rich in cones is called macula (Fig. 1(a)). The center of macula is called fovea which is responsible for clear, sharp and detailed vision in the image. When the macula is affected in diabetic patients, it leads to diabetic macular edema (DME) [1]. The two types of macular edema are, non-clinically significant macular edema (non-CSME) and clinically significant macular edema (CSME) [2]. Non-CSME is a mild form of edema in which the locations of exudates are at a distance from fovea and the central vision is not affected (Fig. 1(b)). CSME is the severe form of edema in which the exudates leak out and get deposited very close to or on the fovea affecting central vision of the eye (Fig. 1(c)) [3]. Therefore the automated localization of fovea is important to construct a computer aided diagnostic system for detecting DME. Together with the optic disc; the fovea is a defining element of fundus coordinate systems which are essential to characterize the spatial distribution of retinal features [4].

Localization of fovea has been attempted by several researchers recently. In most of the papers researchers considered fovea as the darkest non vessel region and the distance from the OD centre is approximately 2.5 times of the OD diameter[5]. These assumptions are applicable only for normal, healthy retinal images and not for pathological images. Therefore the fovea localization in pathological image is very difficult or time consuming. The presence of hemorrhages, hard exudates, non-uniform illumination, and the intensity similarity of the vessel and fovea make the automated fovea localization a difficult task [1]. Some of the existing methods can acquire better fovea localization accuracy. However, these methods suffer from lengthy processing time.

This paper presents a novel algorithm for fovea localization in retinal images. In this work, first the main components of the human retina such as blood vessel and optic disc from the input image are extracted. The morphological operations are employed on the gray scale image of the green channel for distinguish the fovea candidates. Then the initial fovea candidates are selected based on intensity information. The candidates' satisfying area, density and distance criteria are considered for final stage. In the final stage, the vessel pixels are calculated on each final candidate and the candidate having lesser vessel pixels is selected as fovea region



Fig.1. Retinal image with different stages of macular edema (a) Healthy retinal image with its main components (b) non-CSME retinal image (c) CSME retinal image

The contribution of this work is that it proposes a fast and effective algorithm that is capable of locating the fovea center not only in normal, healthy images but also in images affected by the diseases such as Diabetic retinopathy (DR) and DME. The intensity based candidate selection of this work ensures the speed of operation. The morphological operation, area and density criterion distinguish the fovea from other dark region. Further the distance criterion and the vessel pixel count on the candidate region reduce the false detection of fovea. We report the experimental results on two publicly available DRIVE [6] and STARE [7] databases and the obtained results are compared with the methods reported recently.

The remaining section of this paper is organized as follows: Section 2 briefly reviews the previous work on fovea localization. Section 3 details the fovea localization process. Experimental results are reported and discussed in Section 4. and Section 5 concludes the paper.

II. RELATED WORK

Intensity and vascular information based macula localization method is proposed by Sagar et al. [8]. They extracted the blood vessels using morphological operation. Then the blood vessel information is combined with the darkest region property of macula for localizing the macula region. This method achieved an average accuracy of 96% on DRIVE and STARE databases. Tobin et al. [9] employed a parabolic model on the vessel structure to identify the angle between the horizontal raphe and the line of symmetry separating the superior and inferior retinal regions of the retina. Then they defined the fovea center to be at 2.5DD along the horizontal raphe. Ying and Liu [10] extracted the retina blood vessel based on local energy function of blood vessel widths and densities and uses it to position the fovea area. They defined the search region as a circle within the main vessel arcades. Then the fovea is localized within the region by using the pixel intensity and vessel density. Chin et al. [4] also extracted the blood vessel and fit the parabolic curve for approximate the region of interest (ROI). Then they evaluated each sample location on the ROI, as the fovea is taken to be about the size of the optic disc and the vessel count on the sample is lesser than all other.

Tan et al. [11] combine both intensity and OD information for localizing the macula. The method uses the OD diameter to define the region of interest (ROI) for macula. Then they detect the macula region by detecting a region in the ROI of retina having low pixel intensity. The method has an accuracy of 98.8%. Sinthanayothin et al. [5] employed a 40x40 template to localize the fovea region on the retinal image subject to the condition that it be an acceptable distance (approximately 2.5 times the OD diameter) from the optic disc center.

A brightness based macula localization method was proposed by Lu et al. [12]. The authors employed line operator to capture the circular brightness profile which gives the location of macula correctly. The method achieved an average accuracy of 100% and 95.4 % on DRIVE and STARE databases respectively. Liang et al. [13] searched the fovea within a 300x300 pixels region centered on the fundus image. They located the fovea therein as the centroid of the largest group of pixels with minimum intensity value. Li and Chutatape [14] searched for dark regions (a circle of radius 1DD) within a pre-defined search region. The search region was approximated by extracting the blood vessel and fitting a parabolic curve on the major vessel. For curve fitting, they have combined the idea of Hough transform and linear least square fitting. Akram et al. proposed a classifier based approach for fovea localization. They found all dark region of retina, and extract the macula features such as; contrast enhanced green channel mean intensity value, area, normalized cross correlation score and OD coordinates. Then a new hybrid classifier as an ensemble of Gaussian mixture model and support vector machine used for improved exudates detection.

Although a number of methods have been proposed for the localization of fovea, still there is a research gap in accurate detection of the centre of the fovea. The accuracy of existing techniques for fovea detection falls down in the presence of other dark regions like hemorrhages. In order to deal with this problem, we propose a complete novel method for the detection of fovea region by taking in to account the basic properties of fovea and its difference from rest of dark lesions.

III. PROPOSED FOVEA LOCALIZATION METHOD

A. Overview of The Methodology

In the first phase of the algorithm, the retinal components such as blood vessel and OD center are localized. The blood vessel are extracted using 2 Dimensional Gabor matched filter followed by simple thresholding technique, then the OD center is localized by combining the intensity and vascular information. In the next phase, the contrast limited adaptive histogram equalization (CLAHE) is employed on the green channel image for enhancing the contrast of fovea region. The other similar region of the fovea, such as blood vessel and hemorrhages are suppressed by applying suitable morphological operations. Then the initial fovea candidates are selected using thresholding, the threshold value is calculated based on the pixel count of the fovea. The candidates' satisfying area, density and distance criterion are considered for final stage. In the final stage, the candidate having lesser vessel pixel is considered as fovea region. The flowchart of the proposed method is depicted in Fig.2.

B. Blood Vessel Extraction

Blood vessel segmentation is done using our earlier proposed method given in [15]. The green channel of the input image is enhanced using CLAHE with suitable clip limit, and the blood vessels are enhanced by employing 2 dimensional Gabor filter on the CLAHE'd image. Finally, the thresholding is applied to extract the binary vasculature. The obtained result of the blood vessel segmentation is shown in Fig.3 (b).

C. OD Center Localization

OD center is also important for the localization fovea, which is done using our earlier proposed method given in [16]. The method combines both intensity and vascular information for localizing the OD and obtains the center of the OD. The initial OD candidates are selected based on intensity information, then the candidates' satisfying area and density criterion are consider for final stage. In the final stage, the entropy of vascular directions on each candidate is calculated; the candidate having maximum entropy value is selected as OD region. The centroid of the selected candidate is considered as OD center. Fig.3(c) shows the result of OD center localization (the black dot represents the OD center).



Fig.2. Flow chart of proposed fovea localization system

Fig.3. Obtained results of blood vessel and OD localization (a) Original fundus image (b) Vessel extracted image (c) OD center (black dot) localized image

D. Fovea Localization

1) Fovea localization algorithm: The algorithm depicts each step of the fovea localization process; the major steps of the algorithm are discussed in the following sub section:

Step 1: CLAHE for contrast enhancement

Step 2: Morphological closing to removal of blood vessels

Step 3: Morphological opening to flatten more fovea region

Step 4: Threshold estimation for candidate selection

Step 5: Initial candidate's selection using thresholding

Step 6: Select candidates' area criterion which are satisfying;

If no candidate selected, increase threshold and go to step 5

Step 7: Select candidates' density criterion which are satisfying;

If no candidate selected, increase threshold and go to step 5

Step 8: Select candidates' distance criterion which are satisfying;

If no candidate selected, increase threshold and go to step 5

Step 9: Count vessel pixel on each candidates' and select a candidate having lesser vessel pixel.

Step 10: Fovea centre: Centriod of the candidate

Step 11: Stop

2) *Preprocessing*: It is observed that fovea is more contrasted in the green channel compared to other channel; therefore the gray scale of the green channel is taken for fovea localization. In order to enhance the image contrast and reduce the effect of non-uniform illumination the histogram based techniques are employed on the green channel image. Fovea is the darkest region in the retina [5], and the intensity of fovea is similar to the intensity of blood vessels and hemorrhages; therefore it is necessary to distinguish and remove other similar region from fovea. The obtained results of various pre-processing stages of non-pathological (DRIVE_10) and pathological (STARE_44) images are shown in Fig.4 and Fig.5.

The histogram equalization (HE) is the common technique for contrast enhancement. The RF images have different bright (OD, exudates) and dark regions (macula, blood vessel and hemorrhages) region therefore the global based contrast enhancement techniques do not produce efficient results. Contrast limited adaptive histogram equalization (CLAHE) is a region based enhancement technique, which resists the effect of other dark and bright regions. In CLAHE the image is divided into NxN tiles and HE is applied locally to each tiles. The clip limit of CLAHE ensures that the local contrast is limited and does not increase to the maximum. However, result of HE increases the background in-homogeneity, a region based Wiener filtering (3x3) is applied to smoothen the background in-homogeneity. Based on the experiment experience, the tile size for CLAHE is set to 5x5 and clip limit is set to .12. The contrast of fovea region is much higher in the CLAHE'd image (See

Fig.4(d) and Fig.5(d)). The CLAHE operation not only increases the contrast of fovea but also the contrast of blood vessels and hemorrhages. In order to remove other similar region from fovea, the morphological operations are employed on the CLAHE'd image.

Mathematical morphology is a nonlinear image processing methodology based on minimum and maximum operations [17] whose aim is to extract relevant structures of an image.

Let g be a grayscale image which is defined as,

$$g(x) = E \to T \tag{1}$$

Where,

x - the pixel position,

 $T = \{0, 1, 2, ..., 255\},$ for gray scale images

Dilation and Erosion are the two basic morphological operators that are defined as,

$$Dilation: [\delta_B(g)](x) = \max_{b \in B(x)} g(x+b)$$
⁽²⁾

$$Erosion: [\mathcal{E}_B(g)](x) = \min_{b \in B(x)} (x+b)$$
⁽³⁾

Where, B is the structuring element, whose shape is usually chosen according to some a priori knowledge about the geometry of the relevant and irrelevant image structures. The purpose of dilation and erosion is to expand light or dark regions, respectively, according to the size and shape of the structuring element [18]. By combining the dilation and erosion, the new set of operators or filters such us closing and opening are obtained that are used for removing the

blood vessels and other similar regions.

$$Closing: g_{closing} = \phi_B = \varepsilon_B[\delta_B(g)] \tag{4}$$

where, B is a disk-shaped structuring element larger than the maximal vessel width. We set B as 15 in all the images of our experiments. This value (i.e. B = 15) was obtained experimentally, and proved to be sufficient to remove the influence of the vessels in all tested images. We obtain the image $g_{closing}$ by performing a grayscale closing operation on g (see Eq. (4)) (as illustrated in Fig.4(e) and Fig.5(e)). Afterwards, in order to flatten the fovea region more, we remove large intensity peaks by applying a grayscale opening to $g_{closing}$

obtaining $g_{opening}$ (see Eq. (5)).

$$Opening: g_{opening} = \gamma_B = \delta_B[\varepsilon_B(g_{closing})]$$
⁽⁵⁾

where, B is a large disk-shaped structuring element (B = 30). Fig.4(f) and Fig.5(f) illustrates the resulting image $g_{opening}$. The value (i.e. B = 30) was empirically obtained and then used in all the images of our experiments.

3)Threshold calculation: In normal retinal images, the OD generally appears to be circular/slightly oval in shape, and the approximate width and height are 1/8 and 1/7.33 of retinal image diameter (D) [19]. The area of fovea almost equal to the area of OD [20]. Thus the fovea pixel count is calculated as follows:

Estimated fovea pixel count =
$$\frac{\pi^* (D/2)^2}{8*7.33}$$
 (6)

Fig.4. Preprocessing of fovea localization on DRIVE_10 (a) Original fundus image (b) Green channel image (c) Gray scale of green channel image (d) CLAHE'd image (e) Result of morphological closing (f) Result of morphological opening

To obtain an optimal threshold for initial candidate selection, the histogram derived from the input images is scanned from lowest intensity value (1) to highest intensity value (255). The scanning is stopped when the sum of pixels in an intensity level is > Estimated pixel count, and the intensity value at the moment is used as a threshold for initial candidate's selection.

Fig.5. Preprocessing of fovea localization on STARE_44 (a) Original fundus image (b) Green channel image (c) Gray scale of green channel image (d) CLAHE'd image (e) Result of morphological closing (f) Result of morphological opening

4) Area and density criterion: In order to remove the similar candidates such as hemorrhages or other dark regions the area and density criterion are applied on all the initial candidates. According to the area criterion, the pixels in each initial candidate are counted, and the candidates having pixel count more than 125 % or less than 25% of estimated fovea pixel counts are discarded. Then the density criterion is applied on the candidates' satisfying area criterion. According to the density criterion, the candidates having pixel count less than 50% of the number of pixels occupied by rectangle surrounding that candidates are discarded. The obtained results of various stages of fovea localization on a pathological image (STARE_44) are shown in Fig. 6.

5) Distance criterion: The distance criterion is employed on the candidates' satisfying area and density criterion. The width and height of the OD of retinal image varies quite significantly between individuals due to different age and pathology in the eye; therefore the OD to macula distance (DM:DD) should not be taken as a constant. Patients with physiological macro discs (overdeveloped optic disc) usually have a smaller DM:DD ratio (1.84DD) [21] and patients with optic nerve hypoplasia (underdeveloped optic disc appearing abnormally small) have a higher DM:DD ratio (3DD to 4.2DD) [20]. Therefore, in this work we consider a range of value

(1.84DD to 4.2DD) as distance between macula and OD. The candidates within this range of distance are considered for the final stage.

6) Fovea center localization: The candidates' satisfying distance criterion is considered for the final stage. In this stage, the vessel pixels are counted for each final candidate, the candidate having lesser vessel pixel is considered as fovea region. The centriod of the selected candidate is considered as fovea center. The obtained results on each stage of the fovea localization are shown in Fig.6.

Fig.6. Fovea localization on STARE_44 (a) Original fundus image (b) Result of preprocessing phase (c) Initial fovea candidates (d) Candidates satisfying area criterion (e) Candidates satisfying density criterion (f) Candidates satisfying distance criterion (g) Candidate with lesser vessel pixel count (h) Fovea localized image (White dot represent the fovea center)

IV. RESULTS AND DISCUSSIONS

A. Material

The performance of the proposed method is evaluated on publicly available DRIVE (Digital Retinal Images for Vessel Extraction) and STARE (STructural Analysis of REtina) databases. The DRIVE database photographs were obtained from a diabetic retinopathy screening program in Netherlands. The screening population consisted of 453 subjects between 31 and 86 years of age. Each image has been JPEG compressed. The database contains 33 normal and 7 pathological images with exudates, hemorrhages and pigment epithelium changes. The images were acquired using a Canon CR5 non-mydriatic camera with a 45° field of view (FOV). Each image was captured using 8-bits per color plane at 768 by 584 pixels.

The STARE database was composed with the intention to create a difficult database. The database contains 31 images of healthy retinas and 50 of pathological retinas. The pathological images exhibit a wide variety of lesions and other symptoms of diseases. The images were acquired using a TopCon TRV-50 fundus camera at 35° FOV, and subsequently digitized at 605×700 pixels in resolution, 24 bits per pixel.

B. Results on DRIVE and STARE databases

The method was implemented on 3.06 GHz core i3 processor with 3.17 GB RAM using MATLAB 7.6. The proposed method achieved a success rate of 100% (i.e., the fovea was detected correctly in 40 out of the 40 images contained in the DRIVE dataset). Additionally, the fovea was detected correctly in the pathological images of STARE database. The method is fully automatic and localizes the fovea center of one DRIVE image within 2.88 seconds without optimization of its Matlab code. The obtained results on set of DRIVE and STARE databases are shown in Fig.7 and Fig.8 respectively.

The computation time for all the 40 images of DRIVE dataset is reported in Table I. In order to obtain an optimal vessel structure, the vessel extraction algorithm is repeated for several times; therefore the vessel extraction time is differed for healthy and un-healthy retinas. Similarly, the OD localization time differs for

images based on the illumination of the image. The approximate time to localize the fovea centre is .06 seconds, if the assumption on fovea is correct. The average computation time for processing a DRIVE image is only 2.88 seconds.

C. Discussion

In Fig.7, and Fig.8, the results of the proposed method for some retinal images of DRIVE and STARE datasets are shown. In presence of abnormality in the eye, the vascular and OD information are useful and more effective to determine the fovea. Pathological regions like hemorrhages are similar to fovea region in the retina images. Therefore, methods such as brightness-based or template matching or methods which are based on the segmentation results of blood vessels fail to localize the center of fovea in presence of pathological regions in retina image. Despite the existence of dark hemorrhages or bright exudates and pathological regions, the results of the proposed method are satisfactory and it shows the effectiveness of the proposed method for localizing the center of fovea (See Fig.8). In Fig.9, some retinal images with incorrectly detected fovea center are shown. In the first row of Fig.9, there is not any dark region in vicinity of fovea; therefore this method failed to localize the fovea center even though the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are found correctly. Also in the second row of Fig.9 the other anatomic structures are localized or the forea is localized wrongly, because the OD is positioned at the center of the image and it has dark region on both side of the OD with equal distance.

Fig.7. Obtained results on DRIVE database (a) Original fundus image (b) Vessel extracted image (c) OD localized image (Black dot) (d) Fovea localized image (White dot)

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Fig.8. Obtained results on STARE database (a) Original fundus image (b) Vessel extracted image (c) OD localized image(Black dot) (d) Fovea localized image(White dot)

TABLE I Computation Time on DRIVE Images
(a) Image No (b) Vessel Extraction Time in Seconds
(c) OD Localization Time in Seconds (d) Foyea Localization Time in Seconds
(e) Computation Time in Seconds

(a)	(b)	(c)	(d)	(e)	(a)	(b)	(c)	(d)	(e)
1	4.27	0.09	0.09	4.45	21	2.13	0.05	0.06	2.23
2	3.39	0.05	0.08	3.52	22	2.11	0.05	0.06	2.22
3	2.11	0.05	0.06	2.22	23	3.41	0.19	1.20	4.80
4	2.08	0.03	1.91	4.02	24	3.33	0.05	0.06	3.44
5	2.09	0.05	0.06	2.20	25	2.16	0.03	1.25	3.44
6	2.13	0.11	0.06	2.30	26	2.16	0.03	0.08	2.27
7	3.33	0.03	0.06	3.42	27	2.13	0.03	0.06	2.22
8	2.13	0.16	0.06	2.34	28	2.13	0.05	0.06	2.23
9	2.14	0.05	0.06	2.25	29	2.11	0.05	0.06	2.22
10	2.17	0.05	0.06	2.28	30	2.11	0.05	0.06	2.22
11	2.14	0.05	0.06	2.25	31	2.14	0.03	1.61	3.78
12	2.14	0.05	0.06	2.25	32	2.09	0.05	0.06	2.20
13	2.14	0.03	0.06	2.23	33	2.14	0.03	0.06	2.23
14	3.39	0.08	0.06	3.53	34	4.52	0.05	0.33	4.89
15	2.11	0.05	0.19	2.34	35	3.30	0.05	0.06	3.41
16	2.16	0.05	0.06	2.27	36	3.41	0.03	0.08	3.52
17	2.19	0.05	0.06	2.30	37	3.42	0.03	0.08	3.53
18	3.31	0.05	0.06	3.42	38	3.38	0.05	0.06	3.48
19	3.41	0.05	0.06	3.52	39	3.36	0.05	0.06	3.47
20	2.16	0.03	0.08	2.27	40	2.08	0.05	0.06	2.19
Average computation time						2.61	0.05	0.22	2.88

Fig 8. Retinal images with incorrectly detected fovea center (a) RGB fundus image (b) Vessel extracted image (c) OD localized gray scale image (black dot represent the OD position) (d) Fovea localized gray scale image (white dot represent the fovea center)

V. CONCLUSION

Diabetic macular edema is one of the retinal abnormalities that affects the central vision of the person and causes total blindness in severe cases. The algorithm for the automatic and robust extraction of fovea in retinal fundus images was developed in this paper. To begin with, the proposed algorithm extracts the main components of the human retina, i.e. the blood vessels and optic disc for easier localization of the fovea. Then, the region based histogram equalization is employed on the green channel image for enhancing the contrast of fovea region. In order to suppress the other dark region such as blood vessel and hemorrhages, suitable morphological operations were applied. Initial fovea candidates were selected by applying suitable thresholding on the result of the morphological operation. The candidates' satisfying area, density and distance criteria and having lesser vessel pixel are selected as fovea region.

We have evaluated the proposed algorithm on publicly available DRIVE and STARE databases. A significant reduction in computation time and the attainment of useful fovea center localization even in pathological or poor quality images are the most relevant improvements of this work. In addition to giving competitive performance, the proposed approach does not have any parameters to be tuned depending on datasets. The fovea location obtained with this automatic approach will be used as an initial step for the detection of diabetic macular edema.

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