A Simple and Fast Algorithm to Detect the Fovea Region in Fundus Retinal Image

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***Abstract*—Retinal image analysis is one of the crucial topics in medical image processing. During the last three decades, people are trying to extract the different features (like blood vessels, optic disk, macula, fovea etc.) automatically from retinal image. Fovea is one of the important feature of a fundus retinal image. This paper present a simple and fast algorithm using Mathematical Morphology to find the fovea region. Proposed algorithm is based on the structure of the blood vessels and little bit information of the optic disk. We have tested our result on a publicly available DRIVE database and got a comparable results with a state of the art in this area.**
Keywords: Fovea, Macula, Optic Disk, Blood Vessels, Mathematical Morphology.

I. Introduction

Fovea is the most important part of the retina for human vision. If the delicate cones of our fovea are destroyed we become blind. The size of fovea zone in fundus eye image has a relation with various diseases, which may lead to blindness. Usually the zone is approximated to a circle of radius 200 micron [1]. If the said radius is smaller then we can conclude that there may be some deposition at the peripheral side, and that causes some infection or disease in eye, which may tend to retinopathy or blindness. Also the radius of the fovea region may indicate the stages of retinopathy.

Manual detection of fovea region by ophthalmologists is time consuming. Due to unavailability of trained ophthalmologists especially in developing countries like India, automation is highly needed. Fovea is characterized by the center of the macula (see in Fig (1)). In fundus retinal image the macula is the most darkest part approximated by a circle. Geometrically fovea is said to be located at a distance 2.5 times the diameter of the Optic Disk(OD) from its center [2].

Various attempts were made for the successful detection of fovea region. In one of such attempts Sinthanayothin et al. [2] have used a template of size 40×40 with Gaussian distribution with $\sigma = 2.2$. They measure the maximum correlation coefficient between template and intensity image to find the fovea region subject to the condition that it will be an acceptable distance from the OD and in a region of darkest intensity. Chutatape [3] proposed a method based on Parabola fitting on the main blood vessels. In fact many techniques first detect the blood vessels to locate the fovea.

There are several algorithms in the literature for blood vessels detection. People have compared their results through a standard DRIVE database [4]. S. Chaudhury et al. [5] modeled the cross section of a vessel in a retinal image by a Gaussian shaped curve, and then detected using a two dimensional matched filters. Scheme based on active contour model [6], mathematical morphology and curvature analysis [7] have also been tried by the researchers. J. Staal et al. [8] have worked with a method based on extraction on image ridges, which coincide approximately with vessel centerlines. As it appears in the literature, so far the performance of their method is ahead of others with 94.42% accuracy in finding the blood vessels with DRIVE database.

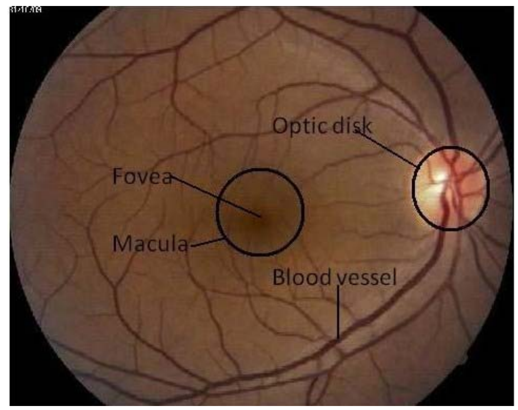


Fig. 1. Illustrates a fundus image

Simo et al. [9] have presented a method based on Bayesian statistical methods that allow to incorporate the domain knowledge. They found the contour of the fovea by means of a unidimensional Markov chain. S. Sekhar et al. [10] have localized the macula region by employing angular information at center of the OD. They have found the macula region by thresholding on the macula candidate region. Here one limitation is that, the macula region should be nearer to the center of the retina image disk. But it can happen that the macula region is far away from the expected location. Then this method will not work properly.

In this paper, we have localized the fovea region in a different way. Our method is focused on the structure of the blood vessels around the macula region. We have used a little bit information of the OD and the blood vessels structure information around the macula region to localize the fovea region further accurately. The proposed algorithm

978-0-7695-4329-1/11 $26.00 © 2011 IEEE
DOI 10.1109/EAIT.2011.22

consists of two parts. In first part, we have detected the blood vessels of the retinal fundus image. In the next stage, we have utilized the geometrical distance between OD and fovea region and the structure of the blood vessels to perfectly localize the fovea region. Rest of the paper is organized as follows. Proposed methodology is presented in the section II. Experiment results and concluding remarks are placed in section III and IVrespectively.

II. Proposed Methodology

A. Blood vessels detection

In fundus retinal image, the blood vessels appeared as a network like structure. The main blood vessels originate from the center of the OD and grow to different branches. In gray-scale fundus image the blood vessels appear in dark shade (see in Fig 2(a)). If we look carefully, there is no vessels around the macula region. We use this feature to find the fovea region.

As our goal is to detect fovea region, we are interested in achieving success in detecting blood vessels to the extent that is sufficient for the second stage. For our purpose 80% accuracy is good enough to carry out the task. We have relied on a Morphology based scheme which is simple enough and fulfills our requirement.

Due to correlation of color information in RGB space we first convert the color fundus image into gray-scale image by Craig's formula in Eq. (1). Let I_1 be the transformed gray-scale image of Fig (1) (see in Fig 2(a)).

$$I_1 = 0.3 \times R \, + \, 0.59 \times G \, + \, 0.11 \times B \tag{1}$$

We apply the gray-scale morphological opening operator (Φ) on I_1 with a flat disc-shaped structuring element of fixed radius three (B_3) (Eq. (2)) to remove small noise(disk with size less than three pixels) and get the final image (say, I_2). Then to eliminate the blood vessels we apply a gray-scale morphological closing operator (Ψ) on I_2 with the similar structuring element of fixed size radius eight (B_8) and obtain I_3 as the final image (Eq. (3)). For closing operation, radius of the structuring element depend on the maximum radius of the blood vessels. As it has been observed that in most of the fundus images of size 565 $\times$ 584, the maximum size of the radius is with in 7 pixels and it has guided us to choose the radius of structuring element as eight.

$$I_2 = \Phi_{B_3}(I_1) \tag{2}$$

$$I_3 = \Psi_{B_8}(I_2) \tag{3}$$

$$I_4 = I_3 - I_1 \tag{4}$$

We have used morphological Top-Hat transformation (Eq. (4)) on I_3, which gives two types of information , one is blood vessels(high contrast) and another one is totally dark region. By Top-Hat transformation we obtain the image I_4. The image, I_4 is binarized by considering zero as the threshold value. There may be some noise in the binary image. To reduce the noise we use the connected component analysis on binary

(a) (b)

Fig. 2. (a): Gray-scale image (b): Blood vessels of image 2(a)

image and finally, obtain the blood vessels as shown in Fig 2(b). Thus, the algorithm is as follows.

Input: Color fundus image.
Output: Image containing only the blood vessels.
Step 1 To reduce correlated color information, convert RGB image to gray-scale.
Step 2 Apply morphological opening operation with a disk shaped structuring element on gray-scale image to reduce the small noise.
Step 3 Use morphological closing operation to remove the vessels structure.
Step 4 Use Top-Hat transformation to extract the vessels like structure.
Step 5 Binarize the resultant image by thresholding.
Step 6 By connected component analysis, reduce the noise of arbitrary shape.

B. Fovea localization

As it has been discussed earlier, once the blood vessels are detected, the proposed scheme tries to localize the fovea. In this effort the scheme relies on information regarding optical disk (OD). Thus it becomes essential to detect OD. In our scheme, the accuracy of such detection is not very essential as it deals with certain average global information of the disk.

There are various works reported in the literature related to OD segmentation. Foracchia et al. [11] have detected the position of the OD based on the preliminary identification of the main retinal vessels. In [12], Aliaa et al. have used a Gaussian matched filter to find the direction of the main blood vessels and the segmented main blood vessels are thinned and filtered to represent the OD center. Hajer et al. [13] have used Water-snake to localize the OD.

Recently Welfer et al. [14] have proposed a scheme to determine the center and contour of the optic disk using adaptive mathematical morphology. We adopt this method in our scheme. Once the major blood vessels are identified, an iterative algorithm is deployed to determine the position of OD which is either in the left or in the right side of the image. Then the centroid (C_x, C_y) of the blood vessels is computed. A vertical line through the centroid is taken as the reference line. All the vessels located in the temporal side (opposite side) of OD and beyond the reference line are removed. Retained vessels are skeletonized and pruned to obtain the parabola

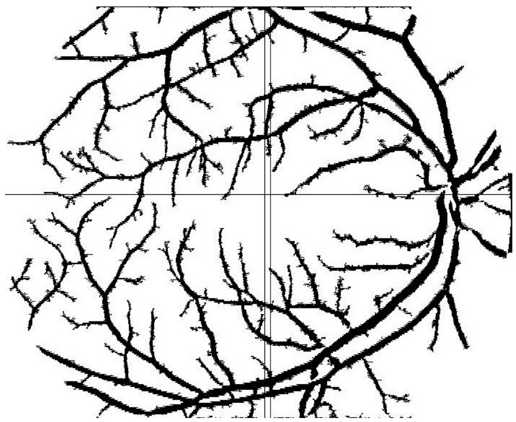


Fig. 3. Horizontal line and vertical strip

shaped vessel. The point where the horizontal line passing through the centroid (C_x, C_y) and parabola denoting the vessel intersecting each other is taken as the center of OD. The OD contour is determined by using Watershed transformation with internal and external markers. Once the center and contour of the optic disk are obtained, the diameter (d) of the disk can be easily computed. However, for the proposed scheme to localize the fovea region, a gross estimate of center and diameter is sufficient. Thus, any point around the actual center can work for us. Moreover, literature indicates that a good estimate of the diameter can also be obtained from the size of the fundus image itself [2].

To localize the fovea region, we start with the image, I_5 containing only the blood vessels as shown in Fig 2(b). Let, G be the approximated center of the OD. P be the point on the horizontal line passing through the center at a distance $2.5 \times d$ in the direction of centroid. As indicated in the literature, P lies in the vicinity (may be above/below/within) of the macula region. In order to extract the fovea region, a strip of width k pixels through the point P (take P as middle of the strip) in a direction perpendicular to the line GP (as shown in Fig (3)) is considered. We rely on the fact that the fovea region is free from any vessel. A sliding window of size k×k is applied along the strip starting from point P in upward and down ward direction. A chain of number is obtained where the number denotes the count of black pixels lying in the window. Finally, the maximum run length of zeros in the chain enables us to localize the fovea region. In our experiment k is taken as nine.

Let, S and E be the start and end position of the maximum run length of zero's respectively and D be the mid position of S and E. The circular region with radius DS and centered at D is the region of interest. To determine the said region of interest, a binary image BW of size same as that of the input image (I_1) with single black pixel at position D and it is dilated by a flat disc of radius DS to obtain BW_d. Pixels extracted from original gray-scale image, I_1 corresponding to the black region in BW_d will form the region of interest, R as shown in Fig 4(a). R is binarized (as shown in Fig 4(b)) by

(a) (b)

Fig. 4. Candidate region (a): Region of interest (b): Thresholded image of 4(a)

selecting the threshold following Otsu's method. The black portion approximates macula region. It is further refined by removing the noise and fitting the circle as shown in blue color in Fig (5). The center of the macula is the localized fovea region marked red in Fig (5). Thus, the algorithm is as follows.

Input: Gray-scale fundus image(I_1), an image I_5(contains only blood vessels), approximate center (G) and diameter(d) of the optic disk.

Output: Macula and fovea region.

Step 1 Locate a point P horizontally at a distance 2.5×d from G towards the centroid.

Step 2 Consider a vertical strip of width k pixels around P perpendicular to GP.

Step 3 Apply a k×k sliding window along the strip and form the chain of numbers denoting the black pixels in the window.

Step 4 Find the maximum run length of zeros, L in the number chain.

Step 5 Let S and E are the start and end position corresponding to L and D be the mid position of S and E.

Step 6 Consider a binary image BW of size same as the input image with only a black pixel at position D. Dilate BW by a disc of radius DS to obtain BW_d.

Step 7 Obtain R as the portion of the gray-scale image, I_1 corresponding to the black region in BW_d.

Step 8 Binarize R to approximate macula region.

Step 9 Refine binarized R by removing noise and fitting the circle to obtain final macula region.

Step 10 Detect fovea region as the small area around the center of macula.

III. Experimental results

We have tested our proposed algorithm on a publicly available DRIVE database [4]. The database contains 40 images of size 565×584. As in five images fovea is not visible, we have excluded those and tested our scheme on 35 images. The scheme has detected fovea correctly in 34 images *i.e.*, the success rate is 97.14%. S. Sekhar et al. [10] have also worked with the same dataset. But, the scheme heavily depends on the

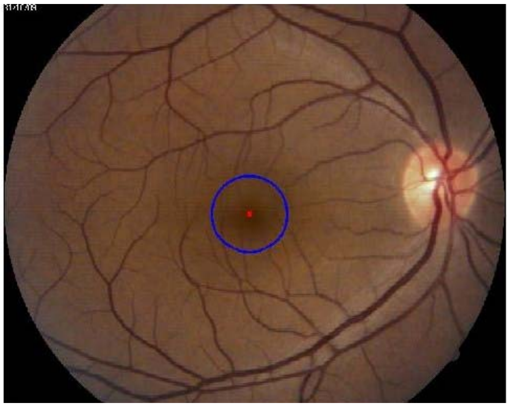


Fig. 5. Macula region (blue color circular region) and fovea (red portion)

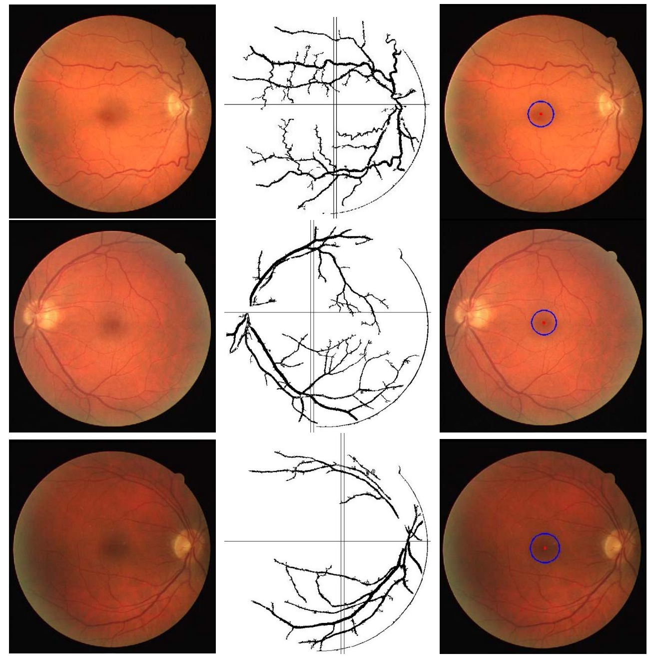
success of optic disk localization. Thus, unlike their scheme, the success of the methodology presented in this work is not critically dependant on such issue. We have also tested on the images of our own database containing 20 images and has achieved 100% success. Few sample results on DRIVE database have been shown in Fig (6) where in each row, first column shows the color fundus images, second column presents the blood vessels of the images corresponding image along with the horizontal line and vertical strip. The extracted macula (blue circular region) and fovea (red region nearer to the center of macula) are shown in last column.

IV. Conclusion

In this paper, we have described a new efficient method to localize the fovea in retinal fundus image. We have used some morphological operators and geometrical features to localize the fovea region successfully. Proposed scheme is simple but efficient in extracting the fovea region. Experiment shows that the outcome the scheme is comparable with others when applied on standard data set. Moreover, it performs well on our own data set consisting of images with variation. Thus, the proposed scheme is robust also. The extracted macula and fovea region may help in further diagnosis of related diseases.

V. Acknowledgements

The author would like to thank Dr. Souvik Banerjee, Asst. Professor of Ophthalmology, Ramakrishna Mission Seva Pratishthan, Vivekananda Institute of Medical Sciences, Kolkata for suggesting this real life problem. He also supplied the image data for our experiment.



(a) (b) (c)

Fig. 6. Experimental results (a): Fundus color image (b): Blood vessels, horizontal line and Vertical strip (c) : Macula (blue circular region) and fovea (red region nearer to the center of the macula)

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