chapter-5

Localization of Fovea in Digital Fundus Images

Detection of the position of anatomical structures is essential in an automatic diabetic retinopathy screening system. Using these locations, a frame of reference can be set up in the fundus image. This is essential for two reasons. 1) To successfully find abnormalities in a fundus image, it is essential to mask out the normal anatomical structures from the analysis; and 2) The distribution of the abnormalities associated with diabetic retinopathy is not uniform over the retina. Certain types of abnormalities occur more often in specific areas on the retina. The position of an abnormality relative to the anatomical structures will be useful as a feature for later analysis. This chapter deals with the detection of vascular arcade, macula and fovea. Macula is located at the centre of retina. It is temporal to the optic disk between the main superior and inferior vascular arcades. Fovea is a small depression in the macula and is indicated by a deep-red or red-brown colour in colour fundus images. It is the darkest part in the retinal images. Accurate localization of the foveal region is important to any diagnosis method that is based on the statistical categorization of vision threatening lesions in the retina. In this chapter, a novel approach for detecting vascular arcade, macula and fovea is proposed and also a polar fundal coordinate system is
established based on the locations of the major anatomical structures of the retina.

The proposed approach consists of five steps. Firstly, the blood vessels are segmented based on HMLRE method proposed in Chapter 3. Next, the optic disk is localized by finding the vessel branch having highest vessel connections. Using the segmented vasculature as input, horizontal raphe of the retina is localized using a model based method [103]. Then the centre of macula (fovea) is determined from the horizontal raphe. Finally, a fundal coordinate system is placed. This chapter is organized as follows. In Section 5.1, the proposed approach to detect vascular arcade, fovea and macula is described. Experimental results of the proposed approach are presented in Section 5.2. Conclusions are given in Section 5.3.

5.1. PROPOSED APPROACH

In this section the implementation details of the proposed approach to detect horizontal raphe, vascular arcade, macula and fovea are illustrated.

5.1.1. Segmentation of Vascular Tree

Blood vessel segmentation based on HMLRE method proposed in Chapter 3 is used to extract the blood vessels in the retina. This method is developed to detect retinal blood vessels using a model that incorporates local linearity of the vessels, piecewise connectivity, and blood vessel brightness with a Gaussian-like profile. The contrast of
the blood vessels is improved by convolving a two dimensional matched filter kernel with the green channel of the histogram matched image. As a blood vessel may be oriented at any angle, twelve 15 x 15 pixel matched filter kernels are applied to convolve with the green channel of the histogram matched image. At each pixel the maximum of their responses is retained. To extract the enhanced segments a local relative entropy based thresholding is applied which takes into account the spatial distribution of gray levels. Connected component labeling is used to identify individual objects in each local relative entropy thresholded image. The Label filtering tries to separate the individual objects by employing the eight-connected neighborhood and label propagation. For the images in Fig. 5.1(a) and (b), the segmented blood vessels are shown in Fig. 5.1(c) and (d).

5.1.2. Localization of Optic Disk

The optic disk is localized by finding the vessel branch with the more number of blood vessels. This method is proposed in chapter 4. The vasculature in the retinal image consists of many vessels of various lengths and various widths. This method converts the detected vasculature into a network of vessels and branches. The information about the connections between vessels and branches is stored in this method. Using this information, the branch with most vessels connected to it can be selected. The selected branch is used to localize the optic disk. The localized optic disks for the images in fig. 5.1 (a) and (b) are shown in fig.5.2.
Fig. 5.1. Segmentation of Blood Vessels. (a) & (b) Colour Fundus Images (c) & (d) Extracted Vessel Network using the HMLRE Method Proposed in Chapter 3.
5.1.3. DETECTION OF VASCULAR ARCADE AND HORIZONTAL RAPHE

The proposed method for detection of vascular arcade relies on the segmented vascular tree and also on the location of optic disk. Determination of the horizontal raphe is very important in the detection of vascular arcade. Horizontal raphe is a line that passes through the centre of optic disk and the fovea which divides the retina into superior and inferior regions. In order to find out an estimate of the vascular arcade, a parabolic model of form \( a.y^2 = |x| \) is applied to the statistical distribution of points defined by the segmented vasculature structure. Let the segmented vasculature is denoted by \( v_i(x, y) \). The location of the optic disk is used to initialize the parabolic shape model in the image space. For data set used in this thesis, the horizontal raphe is distributed over a range of angles, \( \theta \), from \(-45^\circ\) to

Fig.5.2. Detected Optic Disk Locations for the Images Shown in Fig.5.1.
+45° and this angle must be measured in each image to find the macula location accurately. Hence the basic parabolic model of form \( a.y^2 = |x| \) is modified to include an axis rotation \( \theta \) and the known centre of the optic disk \((x_c, y_c)\) as shown in Fig. 5.3.

The points \( P \) that are used to find the parabola are those points in the image where \( v_t(x, y) \neq 0 \) i.e. \( P = \{ (x, y) : v_t(x, y) \neq 0 \} \). Now shifting the parabolic expression \( a.y^2 = |x| \) to the centre of optic disk \((x_c, y_c)\) gives

\[
a.(y - y_c)^2 = |x - x_c|
\]  

\( (5.1) \)
Next to include coordinate rotation, a coordinate transform
\[ x = x' \cos \theta - y' \sin \theta \] and \[ y = x' \sin \theta + y' \cos \theta \] is used which results in

\[ a.\left[ x' \sin \theta + y' \cos \theta - y_c \right] = \left| x' \cos \theta - y' \sin \theta - x_c \right| \]  \hspace{1cm} (5.2)

The above equation can be represented in terms of the transformed coordinate system by noting that, \( x_c = x' \cos \theta - y' \sin \theta \) and \( y_c = x' \sin \theta + y' \cos \theta \) to give

\[ a.\left[ (x' - x_c) \sin \theta + (y' - y_c) \cos \theta \right] = \left| (x' - x_c') \cos \theta - (y' - y_c') \sin \theta \right| \]  \hspace{1cm} (5.3)

Where \((x', y')\) are the coordinates rotated by an angle \( \theta \), and aligning with the horizontal raphe.

Two parameters \((a, \theta)\) should be estimated to decide the parabola of an image. The above equation is nonlinear with respect to the metrics. This equation can be addressed by applying the nonlinear least squares method of Marquardt et al. [104] to estimate the metrics by iteratively minimizing the criterion function \( J(a, \theta) \) on the set of points \( P = \{(x', y') : v_i(x', y') \neq 0\} \) given by

\[ J(a, \theta) = \sum_{(x', y') \in P} a.\left[ (x' - x_c') \sin \theta + (y' - y_c') \cos \theta \right] - \left| (x' - x_c') \cos \theta - (y' - y_c') \sin \theta \right| \]  \hspace{1cm} (5.4)
To initiate the above function \( a = 0.0032 \) and \( \theta = 0 \) are used. The above algorithm converges within seven to ten iterations. An example is illustrated in Fig.5.4 where the rotation angle is 7°.

**5.1.4. Detection of Macula and Fovea**

The candidate region of macula is defined as an area of circle. The centre of macula i.e. fovea is located at 2DD (DD = Optic Disk Diameter) away from the optic disk center along the main axis of fitted parabola. The radius of the candidate macula region is chosen as one optic disk diameter (1DD). As the fovea is positioned at twice the optic disk diameter (2DD) temporal to optic disk in the fundus images [105], the candidate macula region is defined in such a way that the fovea is within this region. The definition of the macula candidate area is illustrated in Fig. 5.5. The detected macula and fovea for the images in Fig.5.1 are shown in Fig. 5.6.

**5.1.5. Establishment of Foveal Coordinate System**

Computer engineers normally use Cartesian coordinates to represent the images, whereas ophthalmologists generally use polar coordinates centered on either optic disk or fovea. In this thesis a polar coordinate system centered on fovea is chosen. This coordinate system is set up based on Early Treatment Diabetic Retinopathy Study (ETDRS) report number - 10 [106]. As per this ETDRS report, a retinal image is divided into ten subfields as illustrated in Fig.5.7.
Fig. 5.4. Example Result of Parabola Fitting on Image in Fig. 5.1(a)

Fig. 5.5. The Approach used for Detecting Candidate Fovea Region
The radii of the three circles centered on fovea from the innermost to the outermost are given by $(1/3)$ DD, 1DD and 2DD respectively [106]. The ten subfields are defined as follows: 1) central subfield within the inner circle; 2) four inner subfields (inferior, superior, temporal and nasal) between the middle and inner circles; 3) four outer subfields (inferior, superior, temporal and nasal) between the outer and middle circles; 4) far temporal subfield, temporal to the outer circle and between 1:30 and 4:30 meridians for the left eyes or between 7:30 and 10:30 meridians for the right eyes.

5.2. EXPERIMENTAL RESULTS

The proposed approach is tested and evaluated on four publicly available databases of colour retinal images: STARE [55], DRIVE [94], DIARETDB0 [101], and DIARETDB1 [102] databases. The motivation
in using different databases is to assess the performance of the proposed approach on fundus images of different high/low pigmentation levels and iris colours found from different patients. The proposed algorithm is implemented using MATLAB 7.4 on a core 2 Duo 1.8 GHz PC with 1GB memory.

The sample results of the proposed approach are presented in Fig.5.8. The images demonstrate that the proposed approach is fairly robust to detect macula and fovea in the presence of pathologies and bad illuminated regions that have similar appearance to fovea. Overall

Fig.5.7. Polar Fundal Coordinate System Centered on Fovea According to ETDRS Report Number-10 [108].
Fig. 5.8. Successful Detection of Macula and Fovea. (a) Normal Retinal Image (b), (c) and (d) Retinal Images containing pathologies and (e) Bad Illuminated Retinal Image.
the detection rates are 100%, 99.2%, and 100% on DRIVE, DIARETDB0 and DIARETDB1 databases respectively. For STARE database, the proposed approach yielded a detection rate of 80.47%. The reason for reduction in detection rate is that in fifteen images of STARE database either the optic disk or the fovea are significantly occluded or missed. The detection rates of the proposed approach are given in Table 5.1. A failure case of proposed approach is shown in Fig. 5.9. This image is from STARE database having central retinal vein occlusion, characterized by optic nerve swelling, diffuse retinal hemorrhages and erythema.

5.3. CONCLUSIONS

This chapter presents an approach to detect vascular arch, macula fovea and establishes a polar fundal coordinate system centered on fovea. The proposed approach consists of five steps. Firstly, the blood vessels are segmented. Next, the optic disk is localized. Using the segmented vasculature as input, horizontal raphe of the retina is localized. Then macula and fovea are detected from the horizontal raphe. Finally, a polar fundal coordinate system is established centered on fovea. The proposed method is tested on all the 360 images from the databases and achieves an average detection rate of 94.86%. The proposed approach is robust to the presence of pathologies and bad illuminated regions that have similar appearance to fovea. The results obtained demonstrate that the proposed system can be adapted for clinical purposes.
Fig. 5.9. Failure Case of Proposed Approach. A Retinal image from STARE Database with a central retinal vein occlusion, characterized by diffuse retinal hemorrhages, optic nerve swelling, and erythema.

Table 5.1. Detection Rates of the Proposed Approach

<table>
<thead>
<tr>
<th>Database</th>
<th>Number of Images</th>
<th>Detection rate in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIVE</td>
<td>40</td>
<td>100</td>
</tr>
<tr>
<td>DIARETDB0</td>
<td>130</td>
<td>99.2</td>
</tr>
<tr>
<td>DIARETDB1</td>
<td>89</td>
<td>100</td>
</tr>
<tr>
<td>STARE</td>
<td>81</td>
<td>80.47</td>
</tr>
</tbody>
</table>