A Gaussian Mixture Model Based System for Detection of Macula in Fundus Images

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Abstract. Digital fundus imaging is used to diagnose various eye diseases like diabetic retinopathy, diabetic maculopathy and age related macular degeneration. Macula is the main central part of retina which is responsible for sharp vision and any changes in macula cause severe effects on vision. In this paper, we propose a novel method for automated detection of macula from digital fundus images. The proposed system performs preprocessing, optic disc detection and blood vessel segmentation prior to macula detection. In macula detection, it formulates a feature vector and uses Gaussian Mixture Model for detection of macular region. We evaluate the proposed technique using publicly available fundus image database MESSIDOR. The results show the validity of proposed system and are found to be competitive with previous results in the literature.

Keywords: Digital fundus imaging, Diabetic maculopathy, Macula, Gaussian Mixture Model.

1 Introduction

The research in medical imaging is of great significance in this modern era. The study in this field has been beneficial to the health care systems and society over many years. Diabetes is one of the lifelong and chronic diseases having many risks. A complication of diabetes known as diabetic retinopathy (DR) is a foremost reason of sightlessness. With the passage of time, the diabetic patients develop DR which causes the leakage of tiny blood vessels in the retina. Healthy retina plays a major role in attaining a good vision.

Macula is the central portion of the retina which is usually the darkest portion and is rich in cones. Macula is accountable for the clear, sharp and detailed vision [1]. The center of macula is called fovea which is responsible for very fine details in the image. The significance of identifying macula is that it is used for the early detection of various diseases. These diseases include age related macular degeneration (AMD) and maculopathy (also called diabetic macular edema) [1].

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Maculopathy is a condition in which the macula develops swelling and a leakage of fluid occurs, causing blurness in the vision. Hence the accurate localization and detection of macula is very important in order to treat these conditions [2]. Ophthalmologists use fundus images for the detection of macula. A normal fundus image contains, optic disc, blood vessels, macula and fovea as its main features. Figure 1 shows the fundus image from different retinal features.

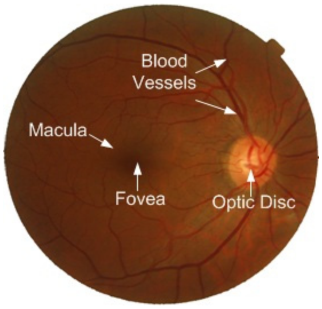

Fig. 1. Fundus image with its main features

Automated detection of macula is vital for the screening of diseases like maculopathy and AMD. There are various computerized methods in the literature which are useful for the detection of macula. Usually macula is the darkest region in the retina. Hence this property is mostly combined with other features of retina like segmented blood vessels in order to localize the macular region [3]. In the method proposed by [3], the blood vessels are segmented using morphological operations followed by thresholding. The method achieved an average accuracy of 96% on DRIVE and STARE databases. The macula is usually located in the vicinity of OD. The methods give high accuracies on databases of DRIVE, STARE and ARIA. A coordinate system establishment method is proposed by Li et al. [4] for the macula localization. The method was tested on some local database and achieved 100% accuracy. Another method proposed by [5] is based on correlation or matching. This technique was tested on some local dataset and the sensitivity and specificity were found to be 80.4% and 99.1% respectively. Another method uses the height of optic disc computed by ARGALI method to define ROI for macula localization [6]. The macula detection is done by identifying the area in the ROI having low pixel intensity. The algorithm has an accuracy of 98.8%. [7] proposed an automated macula detection using line operator. Line operator is employed to capture the circular brightness profile which evaluates brightness variation along different line segments and whose orientation gives the location of macula correctly. The method is tested on DRIVE and STARE databases and achieved an accuracy of 100% and 95.4 % respectively.

This paper is organized in four sections. Section 2 consists of systematic overview of our proposed methodology for the detection of macula. Experimental results are given in section 3 followed by conclusion in section 4.

2 Experimental Methodology

In this section, we describe in detail our proposed method for the detection of macula. The systematic overview of our technique for macula detection is given in figure 2. First of all the input retinal image from the database is taken and preprocessing is applied to improve the background and remove noise from the input image. Then Optic Disc (OD) and blood vessels are segmented and finally they are used for macula detection along with the property that macula is the darkest region in the retinal image.

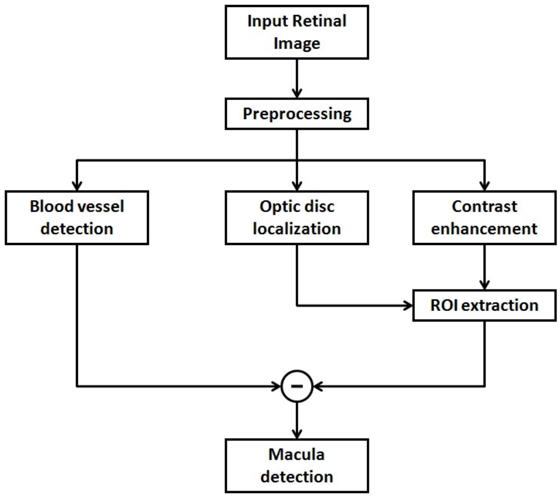

Fig. 2. Flow diagram of the proposed method

2.1 MESSIDOR Database

In this study a publicly available database named MESSIDOR has been used. This database has been established to facilitate computer aided DR lesions detection [18]. The database is collected using TopCon TRC NW6 Non-Mydriatic fundus camera with 45^o FOV and resolutions of 1440×960, 2240×1488 or 2304×1536 with 8 bits per color plane. It contains total 1200 images which are divided into three sets of 400 images and each set is further divided into 4 parts to facilitate thorough testing.

2.2 Preprocessing

Preprocessing is required to extract the fundus image from background and to enhance its quality by removing noisy areas. The processing of background and noisy area from the retinal image is a time consuming process. Hence, background and noise masks are applied to the fundus image to remove the background and noise. The preprocessing phase uses mean and variance based segmentation method for background estimation and HSI(Hue, Saturation, Intensity) based method for noise removal. The details of the preprocessing technique are given in [9].

2.3 Optic Disc Detection

Automated system for macula detection uses Optic Disc (OD) location to find macula from retinal image. OD is a bright yellowish disc in human retina from where the blood vessels and optic nerves emerge [8]. The OD is localized by using averaging filter and image histogram values. Region of interest (ROI) for optic disc is extracted using localization technique and OD is then detected by using a circular Hough transform. The localization and detection of OD is done by applying technique as described in [10].

2.4 Blood Vessel Segmentation

Accurate blood vessel segmentation is also very important for detection of macula and their reliable extraction can reduce the number of spurious regions. In proposed method, we extract vascular pattern by using Gabor wavelets and multilayered thresholding technique as described in [11]. The significance of this technique is that it can segment out even fragile and thin vessels. Figure 3 shows the results of preprocessing, optic disc localization, blood vessel enhancement and segmentation.

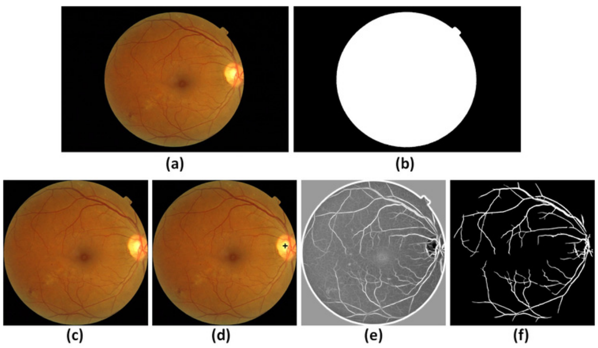

Fig. 3. a) Original retinal image; b) Background removal mask for preprocessing; c) Preprocessed image; d) Optic disc localization; e) Blood vessel enhancement; f) Blood vessel segmentation

2.5 Macula Detection

Diabetic maculopathy and age related macular degeneration are eye abnormalities that directly affect macula resulting in distorted central vision. Hence the detection of macula is very important so that these diseases can be detected at an early stage. Here, our proposed macula detection stage is explained along with its various components

Formulation of Feature Vector. Macula is the darkest region on the surface of retina and can easily be located by looking at the image. However the presence of blood vessels and other retinal abnormalities can make the detection difficult for automated system. The center of macula (also called fovea) is located at a distance of approximately 2.5 times from the OD center. We have used all these properties to build fine descriptors for accurate detection of macula.

We extract the candidate regions for macula detection prior to feature formulation. We apply morphological opening operation first in order to remove the bright regions and abnormalities from surface of retina. This gives us a smooth fundus region containing dark regions only but they need contrast enhancement. The objective of contrast enhancement is to improve the contrast of dark regions for easy detection using a $w \times w$ sliding window, with an assumption that w is large enough to contain a statistically representative distribution of macula [5]. The binary candidate regions for macula are extracted from contrast enhanced image by applying a low adaptive threshold value T using OTSU algorithm[12]. Figure 4 shows the output images as a result of the above mentioned steps.

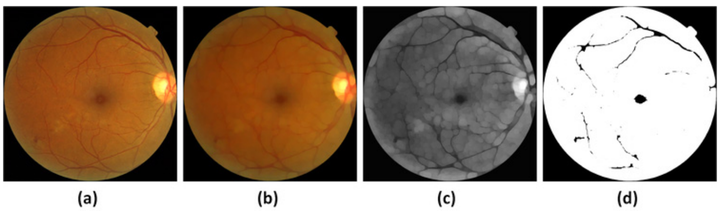

Fig. 4. Candidate Region Detection: a) Preprocessed image; b) Morphological opening; c) Contrast enhanced green channel; d) Binary map containing candidate regions

The binary map segmented by thresholding of contrast enhanced image contains blood vessel and lesion pixels other than macular region due to their similarity with macula. For accurate detection of macula, these false and spurious pixels should be removed before the classification stage. We further use a template matching technique based on Normalized Cross Correlation (NCC) to generate a score for each candidate region [5]. A template having similar intensity value as that of macula is used to approximate macula and fovea. The template is given in equation 1 [5]

$$T(i,j) = 128[1 - \frac{1}{2}e^{(\frac{-(i^2+j^2)}{2\sigma^2})}] \tag{1}$$

We have assumed that the template follows Gaussian distribution where (i,j) is the center of the template and based on certain experiments, the size of this template is 40×40 pixels with $\sigma = 22$. The maximum value of NCC is used to generate NCC score for each region. The feature vector for each candidate region which we feed to the classifier is calculated using vascular map, OD location, mean value of enhanced intensities and NCC score for that region.

Classification. The binary map generated in last step may contain spurious regions such as haemorrhage and vessel pixels. The classification stage takes a candidate region and classifies it into macular or non macular region. We use Gaussian Mixture Model (GMM) for classification which is a linear and weighted combination of different Gaussian distributions [13]. The feature vector consisting of five features is passed to the GMM. We define two classes such as $C_1 = \{Macular\ Region\}$ and $C_2 = \{NonMacular\ Region\}$. Figure 5 shows the classification process for our proposed system.

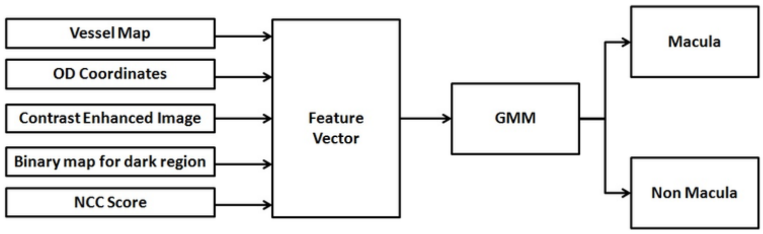

Fig. 5. Flow diagram of classification stage

In our proposed system, GMM makes decision using Bayesian decision rule which is stated as [14]

$$\begin{aligned} &Choose \quad C_1 \quad if, p(\mathbf{x}|C_1)P(C_1) > p(\mathbf{x}|C_2)P(C_2) \\ &otherwise\ choose\ C_2 \end{aligned} \tag{2}$$

where $p(\mathbf{x}|C_i)$ is the likelihood and $P(C_i)$ is the prior probability of class C_i which is calculated as the ratio of class C_i samples in the training set. We apply Expectation Maximization (EM) to find the best value γ which is number of mixtures in GMM. The EM is an iterative method which chooses the optimal value of γ by finding the local maximum value of GMM likelihood for training data. EM finds such value of γ for which mixture of κ weighted Gaussians can represent the data accurately. In our case the value of γ is 10.

3 Experimental Results

The proposed system is tested and evaluated properly to check the validity of proposed method. We have used percentage accuracy as a measure of merit for our proposed system. The accuracy is computed as a ratio of images in which macular regions are correctly classified to the total number of images. Table 1 shows the comparison of proposed system with existing methods in the literature. The table shows that our proposed system yields competitive results as compared to other results in the literature. It is to be mentioned that the number of images in MESSIDOR database is much bigger as compared to the number in other databases mentioned in Table 1. The proposed method extracts the macular region correctly in 1164 images out of total 1200 images.

Table 1. Performance evaluation of our proposed system as compared to other methods for detection of macula

Method	*Database*	*No. of Images*	*Accuracy* (%)
Sagar et al. [3]	DRIVE & STARE	121	96
Li et al. [4]	Local	143	100
Sinthanayothin et al. [5]	Local	112	90
Tan et al. [6]	Local	162	98.8
Lu et al. [7]	DRIVE & STARE	121	97.7
Proposed Method	MESSIDOR	1200	97.2

Our proposed system finds macula with high accuracy even in the presence of different abnormalities and distorted images. Figure 6 shows the pictorial results of macula detection in fundus images with different variations. It shows that the proposed system detects macula even in presence of different abnormalities. It also shows a case in which the system fails to detect macula accurately because of wrong OD localization (last image on right bottom of fig. 6).

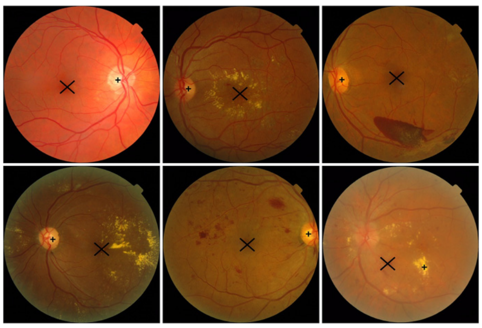

Fig. 6. Macula detection using proposed system for different fundus images

4 Conclusion

Macula detection is very significant in the automated screening system for maculopathy. It will help in early detection of different abnormalities like macular edema and AMD. The macula detection technique proposed in this paper consists of preprocessing of fundus image, OD and blood vessel segmentation followed by macula detection using GMM. A feature vector consisting of vessel map, OD coordinates, contrasted enhanced intensity, binary map and NCC score is used to represent each candidate region. Macula detection using our proposed method has been done for the first time on MESSIDOR database. The results have shown the significance of our proposed system and are proved to be competitive when compared with other results in the literature.

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