An Automated System for the Grading of Diabetic Maculopathy in Fundus Images

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Abstract. Computer aided diagnosis systems are very popular now days as they assist doctors in early detection of the disease. Diabetic maculopathy is one such disease which affects the retina of the diabetic patients. It affects the central vision of the person and causes blindness in severe cases. In this paper, an automated system for the grading of diabetic maculopathy has been developed, that will assist the ophthalmologists in early detection of the disease. Here, we propose a novel computerized method for the grading of diabetic maculopathy in fundus images. Our proposed system comprises of preprocessing of retinal image followed by macula and exudate regions detection. This is followed by feature extractor module for the formulation of feature set. SVM classifier is then used to grade the diabetic maculopathy. The publicly available fundus image database MESSIDOR has been used for the validation of our algorithm. The results of our proposed system have been compared with other methods in the literature in terms of sensitivity and specificity. Our system gives higher values of sensitivity and specificity as compared to others on the same database.

Keywords: Computer aided diagnosis systems, Diabetic maculopathy, Fundus images, SVM classifier.

1 Introduction

Over the years, medical imaging has become a significant part in early detection of various diseases. It is the fastest growing area within medicine and research at present and plays a central role in developing cost effective health care systems. Diabetes is one of the chronic disease all over the world. Diabetic retinopathy (DR) is a condition where diabetes starts effecting the human retina. There are several stages of diabetic retinopathy namely non proliferative DR, proliferative DR and diabetic maculopathy (commonly known as macular edema) [1].

Macula is the central portion of the retina which is usually the darkest portion and is rich in cones [1]. Macula is accountable for the clear, sharp and detailed

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vision. When the damaged blood vessels in the retina leaks out and the fluid gets deposited near macula, then it leads to distorted central vision. Exudates are the yellow color deposits of protein present in the retina, and maculopathy occurs when exudates affect the central vision. The ophthalmologists grade maculopathy into two stages i.e. Non Clinically Significant Macular Edema (Non-CSME) and Clinically Significant Macular Edema (CSME) [2]. Non-CSME is a mild form of maculopathy where there are no symptoms of the disease. Because in Non-CSME, the location of exudates are at a distance from fovea, so the central vision is not affected. CSME is the severe form of maculopathy, in which the exudates leak out and get deposited very close to or on fovea, affecting central vision of the eye [2]. Figure 1 shows the retinal images having different types of macular edema.

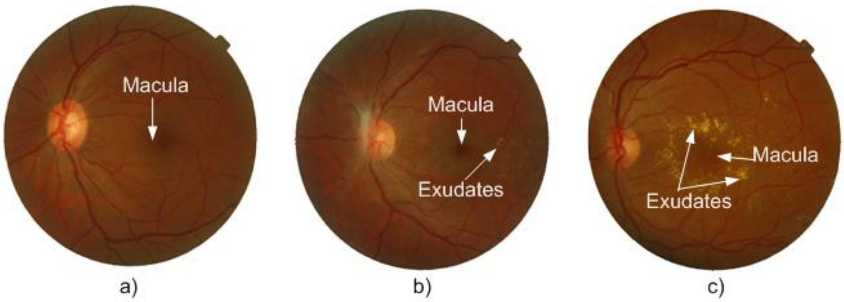

Fig. 1. Stages of diabetic maculopathy: a) Healthy retinal image, b) Non-CSME retinal image, c) CSME retinal image

Irrespective of diabetic retinopathy, long term diabetic patients have chances of developing diabetic maculopathy. Automated detection of diabetic maculopathy is vital for the early cure of the disease. There are various computerized methods in the literature which are useful for the detection of diabetic maculopathy. In [3], diabetic maculopathy is graded by location of exudates in marked region of macula in fundus image. Exudates are detected using clustering and mathematical morphological techniques. The method is tested on local dataset and the sensitivity and specificity are found to be 95.6% and 96.15% respectively. [4] proposed an intelligent diagnostic system for diabetic maculopathy using fundus images. The feed forward artificial neural network is used for classification. They have stated a sensitivity value of 95% and specificity value of 100%. In [5], marker controlled watershed transformation is used for exudates feature extraction and diabetic macular edema classification. The exudates from the fundus image are extracted, and their location along with marked macular regions is utilized for the classification of macular edema into different stages. The method is tested on MESSIDOR database and the sensitivity is found to be 80.9% and specificity is 90.2%. Deepak et. al [6] proposed a method for automatic assessment of macular edema using supervised learning approach to capture the global characteristics in fundus images. Disease severity is assessed using a rotational asymmetry metric (motion pattern,) by examining the symmetry of macular region. The method is tested on publicly available databases like diaretdb0, diaretdb1, MESSIDOR and DMED. The accuracy for the maculopathy detection is found to be 81%. [7] presented a method for classification of exudative maculopathy. This technique uses FCM clustering and artificial neural networks. The authors have reported sensitivity of 92% and specificity of 82% on some local dataset.

This paper is organized in four sections. Section 2 consists of systematic overview of our proposed methodology for the grading of diabetic maculopathy. This section also explains the detailed proposed system and its various modules. Experimental results and analysis are given in section 3, followed by conclusion in section 4.

2 Experimental Methodology

In this section, our proposed method and its various stages for the grading of maculopathy are explained in detail. The flowchart of proposed method for the grading of diabetic maculopathy is shown in figure 2. In our work, retinal images present in MESSIDOR database are used, which are then preprocessed. Afterwards, macula and exudates region detection is performed, and based on them a feature set is formulated. The feature set is then classified with SVM classifier to grade the fundus image into its different types.

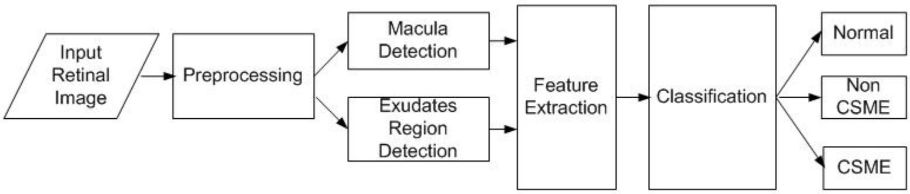

Fig. 2. Flow diagram of our proposed method

2.1 MESSIDOR Database

The retinal images present in MESSIDOR database has been used in our study. This publicly available database has been established to facilitate computer aided DR lesions detection. 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. Each set contains an Excel file with medical findings which can be use for testing purposes.

2.2 Preprocessing

The acquired retinal image contains extra background pixels which are not required for further processing and add more time in overall processing. The purpose of preprocessing is to differentiate between background and foreground and eliminate background and noisy pixels. A mean and variance based method for background estimation, and ratio of Hue and Intensity channel for noise detection are used in preprocessing. The details of these methods are given in [8].

2.3 Exudates Detection

Exudates are the bright lesions which appear on the surface of retina if the leaking blood contains fats and proteins along with water. Their occurrence is a main threat to vision especially when they occur near or on macula. The presence of Optic Disc (OD) makes it difficult for automated system to detect exudates with high accuracy. The proposed system detects and removes OD pixels for accurate detection of exudates. Followings steps are used for exudate detection [10]:

- Take preprocessed image as an input and apply morphological closing to remove the effect of blood vessels and dark lesions
- Apply adaptive contrast enhancement technique to improve the contrast of exudates on retinal surface
- Create filter bank given in equation 1 based on Gabor kernel and convolve it with contrast enhanced image to further enhance the bright lesions [15]

$$G_{FB} = \frac{1}{\sqrt{\pi r}\sigma} e^{-\frac{1}{2}[(\frac{d_1}{\sigma})^2 + (\frac{d_2}{\sigma})^2]} (d_1(cos\Omega + \iota sin\Omega)) \quad (1)$$

  where σ, Ω and r are the standard deviations of Gaussian, spatial frequency and aspect ratio respectively θ is the orientation of filter and $d_1 = xcos\theta + ysin\theta$ and $d_2 = -xsin\theta + ycos\theta$ [15].
- Create binary map containing candidate exudate regions by applying adaptive threshold value T which is calculated using OTSU algorithm [9]
- Detect OD using averaging and Hough transform given in [11] and remove all OD pixels from binary map.

2.4 Macula Detection

Macula detection is an important module for developing the computerized system for the grading of diabetic maculopathy. It is the macular area of the eye that is affected in diabetic maculopathy upsetting the central vision of the eye and in severe cases leading to blindness. The technique which we have used for macula detection is described in [13]. In this technique macula is first localized with the help of localized OD and enhanced blood vessels [12]. Finally macula is detected by taking the distance from the center of optic disk along with enhanced blood vessels image to locate the darkest pixel in this region, and making clusters of these pixels. The largest cluster formed is macula [13]. Figure 3 shows the outputs of different modules, i.e. preprocessing, exudate and macula detection.

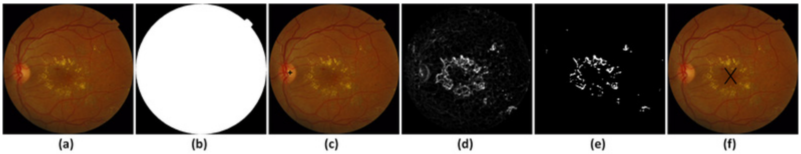

Fig. 3. a) Original retinal image; b) Preprocessing mask; c) OD detection; d) Filter bank response; e)Binary map for exudates; f)Macula detection

2.5 Feature Extraction and Classification

The binary map generated in exudate detection phase may contain spurious and non exudate regions. A feature set for each object in binary map consisting of area, mean intensity value, energy and mean value of filter bank response is created to find true exudates. Exudates are used to grade the risk of macular edema. Table 1 shows the three diabetic maculopathy grading conditions which have been used while designing MESSIDOR database. We have used Support Vector Machine (SVM) classifier to grade the input image. The complete feature vector containing features for exudates and location of macula is passed to SVM, where it grades the test image into three categories as defined in table-1.

Table 1. Conditions for grading of diabetic maculopathy [16]

Grade	*Condition*	*Class*
0	No exudate present	Normal
1	A few exudates present and distance between macula and exudates $>$ one papilla diameter	Non CSME
2	Exudates present and distance between macula and exudates $\leq$ one papilla diameter	CSME

Support Vector Machine (SVM) separates the exudates and non exudates regions from each other with maximum margin by using a separating hyperplane. Let the separating hyperplane be defined by $x \cdot w + b = 0$, where w is its normal. For linearly separable data labeled x_i, y_i, $x_i \in R^{N_d}$, $y_i = \{-1, 1\}$, $i = 1, ..., N$, the optimum boundary chosen with maximum margin criterion is found by minimizing the objective function using equation 2.

$$E = \parallel w \parallel^2, \tag{2}$$

subject to $(x_i \cdot w + b)y_i \geq 1$, for all i. We apply linear SVM for classification of exudates, hence the inequality in equation 2 doesn't hold in that case. The new objective function is defined in equation 3.

$$E = \frac{1}{2} \parallel w \parallel^2 + C \sum_i L(\xi_i), \tag{3}$$

subject to $(x_i \cdot w + b)y_i \geq 1 - \xi_i$, for all i.

$C\sum_i L(\xi_i)$ is the empirical risk associated with misclassified cases where L is a cost function and C is the parameter that minimizes the risk against maximizing the SVM margin.

The linear cost function is robust to outliers hence equation 1 is generalized by taking $L(\xi_i) = \xi_i$ in equation 4.

$$\alpha^* = \max_{\alpha}(\sum_i \alpha_i + \sum_{i,j} \alpha_i \alpha_j y_i y_j x_i.x_j), \tag{4}$$

subject to $0 \leq \alpha_i \leq C$ and $\sum_i \alpha_i y_i = 0$ in which $\alpha = \{\alpha_1, ..., \alpha_i\}$ is the set of Lagrange multipliers. The optimum decision boundary ω_0 which is a linear combination of all vectors is given in equation 5.

$$\omega_0 = \Sigma_i(\alpha_i y_i x_i) \tag{5}$$

This decision boundary is then used to classify candidate object into exudate and non exudate region. The final output of SVM depends on macular coordinates and their distance from exudates if present.

3 Experimental Results

The proposed system is tested and evaluated properly to check the validity of proposed method. The SVM grades the images into different categories depending on the number and position of lesions. Figure 4 shows different images classified as normal, Non-CSME and CSME by the classifier.

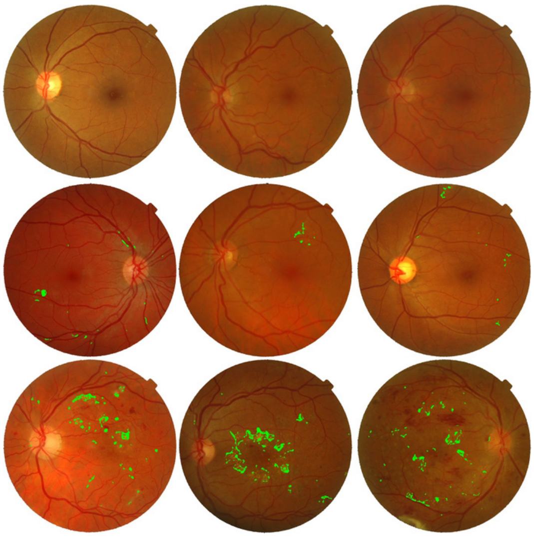

Fig. 4. Maculopathy detection. 1st row: Normal images; 2nd row: Non-CSME or grade 1 images; 3rd row: CSME or grade 2 images.

We have used sensitivity, specificity and accuracy as the figures of merit for performance evaluation. Sensitivity and specificity are the true positive and true negative rates respectively and accuracy is the ratio of truly classified images to the total number of images. Table-2 shows the comparison of our proposed system with existing methods in the literature in terms of sensitivity, specificity and accuracy. The results show that our proposed method achieved high values of sensitivity, specificity and accuracy as compared to other methods using MESSIDOR database. Furthermore, the results from other methods are comparable with our method as we are using a large dataset of images than [3], [4] and [7].

Table 2. Comparison of our proposed method with existing techniques

Author	*Technique*	*Database*	*Sensitivity*	*Specificity*	*Accuracy%*
Siddalingaswamy et. al. [3]	Clustering and morphology	Local dataset	95.6%	96.15%	-
Nayak et. al. [4]	Feed forward ANN	Local dataset	95%	100%	-
Lim et. al. [5]	Marker controlled watershed transform	MESSIDOR	80.9%	90.2%	-
Deepak et. al. [6]	Rotational Asymmetric	MESSIDOR	95%	90%	-
	Motion Pattern	DMED	100%	74%	-
Osareh et. al [7]	FCM Clustering and ANN	Local dataset	92%	82%	-
Aquino et. al. [14]	Image Processing	MESSIDOR	-	-	96.51%
Proposed Method	Filter bank and SVM	MESSIDOR	92.6%	97.8%	97.3%

4 Conclusion

In this paper, we have proposed a method for developing computerized system for the grading of diabetic maculopathy. Our proposed system consists of preprocessing, exudates region detection followed by macula detection. The exudate detection stage creates a binary map of candidate regions. The SVM based classifier first detected true exudate regions based on feature set then using coordinates of macula and the distance of exudates from macula, the classifier grades the input image into three categories. The success of computerized diagnostic system mainly depends upon three factors such as sensitivity, specificity and accuracy of the system. The results showed that our system has higher values of sensitivity and specificity on MESSIDOR database as compared to the values in literature, hence making our system significant for the screening purposes.

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