Grading System for Diabetic Retinopathy Disease

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***Abstract*—Diabetic Retinopathy (DR) has become a serious threat to our society causing 45% of the legal blindness in diabetes patients. Early detection as well as the periodic screening of DR helps in reducing the progress of this disease and in preventing the subsequent loss of visual capability. This paper presents an automated grading system for DR based on fundus images. The severity level of DR is classified using features such as microaneurysms (MAs) and hemorrhages (HAs) which are extracted from the fundus images. Based on the experimental results, it is found that the developed system yields remarkable and promising results even though only low-quality images have been used as test images.**

***Index Terms*—diabetic retinopathy, contrast enhancement, H-maxima transform, multilevel thresholding, mathematical morphology**

I. Introduction

DIABETIC Retinopathy (DR) is one of the well-known and commonest eye diseases, affecting patients with diabetes mellitus. DR is potentially considered as the major reason for blindness in adults of age between 20 - 60 years, causing 45% of the legal blindness in patients with Diabetes Mellitus [1]. According to Lee *et al.* [2], blindness due to diabetic eye disease costs about 500 million dollars a year in the United States [3]. As DR is a progressive disease, the longer a patient has untreated diabetes, the higher his chance of progress towards blindness [4]. For this reason, early detection as well as the periodic screening of DR potentially helps in reducing the progression of this disease and in preventing the subsequent loss of visual capability. The screening should be done every six months, which includes obtaining and analyzing a sequence of fundus images and observing the early changes in blood vessel patterns and also the presence of the dark spots, such as microaneurysms (MAs) and hemorrhages (HAs).

It is known that there exists a positive correlation between the number of MAs and HAs and the severity and progression of DR [5]-[8]. MAs are considered as the earliest observable signs indicating diabetic retinopathy. Besides, HAs also play an important role in the early detection of DR. MAs appear as small, round, and dark reddish spots. The smaller size as well as the background intensity variation make the detection of MAs a complicated and problematic task. HAs are also reddish in colour similar to MAs but they are larger in size and arbitrary shaped [9], as can be seen in Fig. 1.

This paper discusses the development of an automated decision support system for DR disease based on the number and location of MAs and HAs. The system starts with the segmentation of MAs and HAs, followed by the classification of these spots. Based on the number of MAs and HAs, the system quantifies the severity level of DR. The proposed segmentation algorithm is based on a number of morphological operations [10], [11], such as dilation, erosion, opening, closing, reconstructions, and top- and bottom-hat. The main components of the human retina are the optic disk, fovea, tissue and blood vessels. Removing these components will help in avoiding the false positives as much as possible. As the retinal images are poorly contrasted, an effective combination of top- and bottom-hat is utilized for enhancing the image contrast. Furthermore, other techniques such as h-maxima transform [10] and multilevel thresholding [12] are exploited to decrease the intensity levels, and consequently, make the dark spot segmentation problem easier. A user-friendly interface is designed in order to enable the user to interact with the developed system.

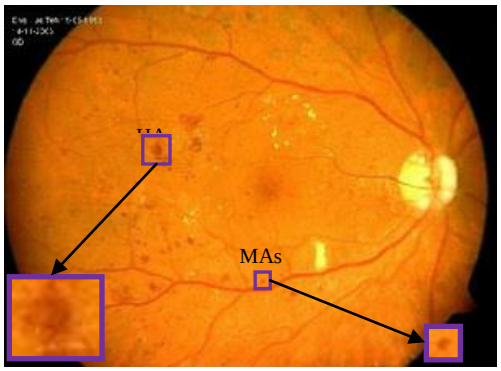

Figure 1. RGB retinal image acquired from one of the DR patients

II. Developed System

In this work, an automated decision support system for Non-Proliferative DR disease is presented. Input to the developed system is a color image of human retina, which is acquired by using a fundus camera, and its outputs are binary images depicting the presence of spot lesions (MAs and/or HAs), and also the severity level of DR. Fig. 2 shows the block diagram of the developed system. A database of 98 low-resolution colour images compressed by JPEG format was used in this work to test the accuracy of the proposed algorithms. The test images

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were collected from the University Malaya Medical Centre (UMMC), which were acquired from patients in different stages of DR. The presence of MAs and HAs was manually marked by a specialist in the test images, and a comparison between the results of our algorithm against the hand-labeled images was done.

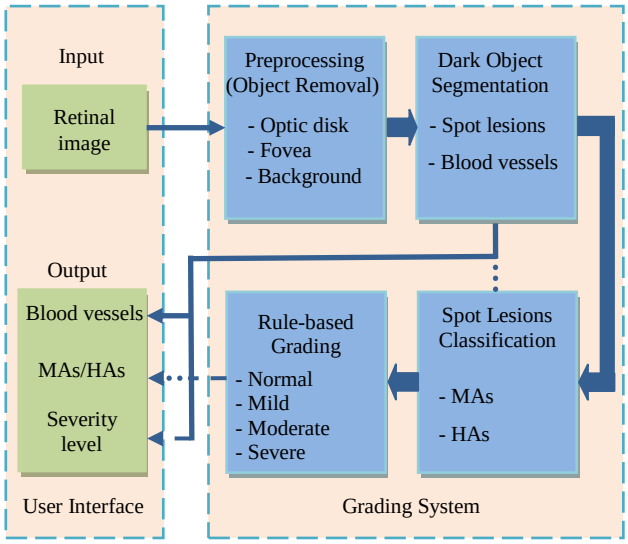


Figure 2. Block diagram of the developed decision-support system for DR disease

A. *Preprocessing*

Pre-processing is a crucial stage for preparing the fundus image for segmentation since image quality varies according to the conditions of acquisition. For instance, the image could be acquired under some undesired conditions, such as unevenly illuminated, noisy or low-contrasted images, which obviously influence the performance of segmentation algorithm. Hence the acquired RGB image has to undergo a sequence of preprocessing steps, which are green-channel extraction [13], optic disk removal [14], and background removal [14].

B. *Dark Spot Segmentation*

In the proposed system, dark spot lesions, namely MAs and HAs, are segmented efficiently using a sequence of stages, which are: h-maxima transformation, thresholding and feature extraction. The resulting image from the pre-processing stage is processed by the h-maxima transform for reducing the number of intensity levels, which will be helpful in the subsequent stages. The h-maxima transform is used for suppressing all maxima in an intensity image I whose values are less than a certain threshold *h* [10].

Thresholding is applied to produce a binary image in which the value of each pixel is either 1 (dark spot) or 0 (background). Unfortunately, there is no unique technique for thresholding which provides perfect results for all images. However, in the proposed algorithm, a multilevel thresholding technique [12] is used to implement the binarization process efficiently. The image undergoes a multilevel thresholding process so that the threshold value can be selected easily. Multilevel thresholding converts an intensity image to an indexed image by decreasing the number of intensity levels. This is performed by separating the pixels of an intensity image into N groups $G_1 \ldots G_N$, based on certain threshold values Ti, as shown below [12]:

$$T_i = \frac{i}{N-1}, \frac{i+1}{N-1}, \ldots, \frac{N-2}{N-1} \qquad i = 1, \ldots, N-1 \qquad (1)$$

Threshold values T_i can be obtained by analyzing the image histogram [12]. Using this technique, a threshold value of T = 100 is selected and a binary image H_{BW} is obtained by thresholding the indexed image H_T, as shown in Fig. 3, by using (2):

$$H_{BW}(x, y) = \begin{cases} 1 & \text{if } H_T(x, y) \geq T \\ 0 & \text{Otherwise} \end{cases} \qquad (2)$$

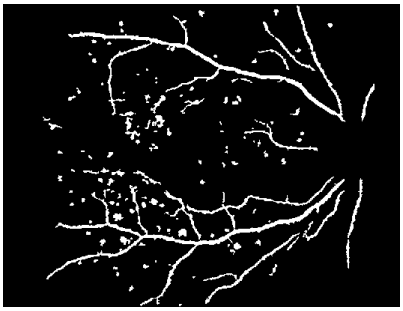


Figure 3. Binary image H_{BW} obtained by thresholding the indexed image H_T

Using a suitable post processing technique [14], blood vessels and other unwanted objects are excluded from the resulting binary image H_{BW} to obtain an image H_S which contains only dark spots, viz MAs and HAs, as shown in Fig. 4.

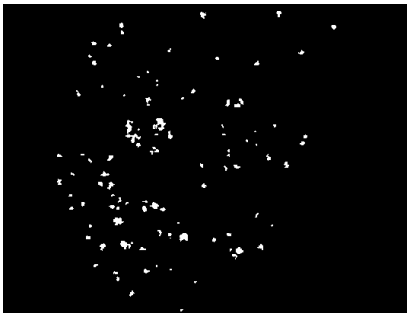


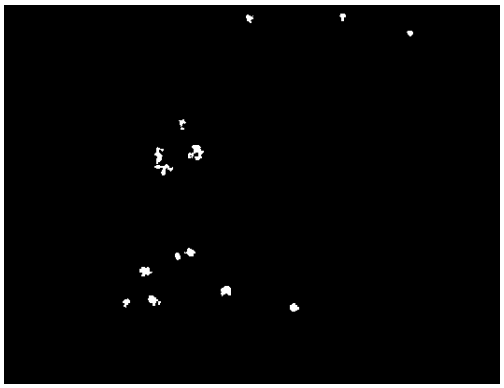
Figure 4. Image H_S obtained after post processing

C. *Dark Spot Classification*

According to the Early Treatment Diabetic Retinopathy Study (ETDRS) [9], [15], classification of the different spot lesions (i.e. cotton-wool spots, hard exudates, drusen, microaneurysms, hemorrhages) can be performed based on seven features, which are: size, shape, roughness, edge sharpness, brightness, colour, and depth. In the current work, we are interested in the classification of MAs and HAs. Among the features above, MAs and HAs are similar with respect to five features, which are dull (roughness), insignificant edge (edge sharpness),

dark (brightness), reddish (colour), and superficial (depth). Hence the classification is mainly based on the remaining two features, i.e. size and shape.

In this work, some straightforward geometric-based criteria [14] are used to classify MAs and HAs. As indicated earlier in the introduction, MAs appear as small and round spots, and therefore, size can be considered as the more significant evidence for classification. Based on some thresholds for the size, an object can be judged whether it resembles MA or HA. Figs. 5(a) and 5(b) respectively show MA or HA which represent the outputs of the proposed classification algorithm.



(a)

(b)

Figure 5. outputs of the proposed classification algorithm (a) Binary image contains HAs (b) Binary image contains MAs

D. Severity Level Grading

TABLE I. INTERNATIONAL CLINICAL DR DISEASE SEVERITY SCALE

Severity level	Findings observable with dilated ophthalmoscopy
Normal	No MAs or HAs
Mild	Microaneurysms only
Moderate	Both MAs + HAs HAs ≤ 20 in 4 quadrants
Severe	Both MAs + HAs HAs > 20 in 4 quadrants

In Non-Proliferative DR, the severity level is classified as normal, mild, moderate, or severe according to the rules shown in Table I [16]. Severity level is said to be "Normal" if there are no abnormalities within the retina. The presence of MAs (no HAs) indicates a 'Mild' condition. The severity level is classified as "Moderate" if a few HAs (less than or equal to 20) are found in addition to MAs. Otherwise, the severity level will be classified as "Severe".

III. RESULTS AND DISCUSSION

The performance of the proposed algorithm was evaluated using a database of 98 low-resolution colour images. The database comprises two sets of images with different sizes. The presence of MAs and HAs within the test images are as follows:

Set 1: 62 images of size 480×640 pixels, the specialist manually marked the locations of 372 individual MAs as well as 217 HAs in the test images.

Set 2: 36 images of size 576×768 pixels, the specialist manually marked the locations of 157 individual MAs as well as 112 HAs in the test images.

A comparison between the results of the proposed segmentation algorithm against the manually-marked images was done in order to measure the performance of the proposed classification algorithm. The performance evaluation was measured based on three statistical criteria, namely, sensitivity, specificity and kappa coefficient, which can be calculated using (3)-(5) respectively [17], [18].

$$Sensitivity = \frac{TP}{TP + FN} \tag{3}$$

$$Specificity = \frac{TN}{TN + FP} \tag{4}$$

$$kappa = \frac{\Pr(o) - \Pr(e)}{1 - \Pr(e)} \tag{5}$$

$$\Pr(o) = \frac{(TP + TN)}{(TP + TN + FP + FN)} \tag{6}$$

$$\Pr(e) = \frac{[(TP + FP) * (TP + FN)] + [(FN + TN) * (FP + TN)]}{(TP + TN + FP + FN)^2} \tag{7}$$

where *TP*, *TN*, *FP*, *FN*, Pr(*o*) and Pr(*e*) represent True Positive, True Negative, False Positive, False Negative observed and chance agreements respectively. Table II presents the experimental results obtained by the proposed algorithm, which reveals that the algorithm yields promising results in terms of sensitivity, specificity and kappa coefficient even though only low-quality images were used as test images. The test images were classified into four groups by the specialist, as shown in Table III. Besides the classification accuracy results, the proposed system yields a severity grading rate of 90.81%, which indicates that 9 images out of 98 were incorrectly graded. It is expected that the proposed system will yield better results if it is tested using high-quality images. Fig. 6 presents a Graphic User Interface (GUI) which has been designed using MATLAB v.7.7.

TABLE II. PERFORMANCE OF THE PROPOSED CLASSIFICATION ALGORITHM

Spot lesion type	Sensitivity (%)	Specificity (%)	Kappa (%)
MAs	84.31	93.63	68.98
HAs	87.53	95.08	74.91

TABLE III. PERFORMANCE OF THE PROPOSED SYSTEM COMPARED TO THE GRADING OF A SPECIALIST

Group	No. of images graded by Specialist	No. of images graded by the proposed system
Normal	22	21
Mild	36	33
Moderate	28	25
Severe	12	10

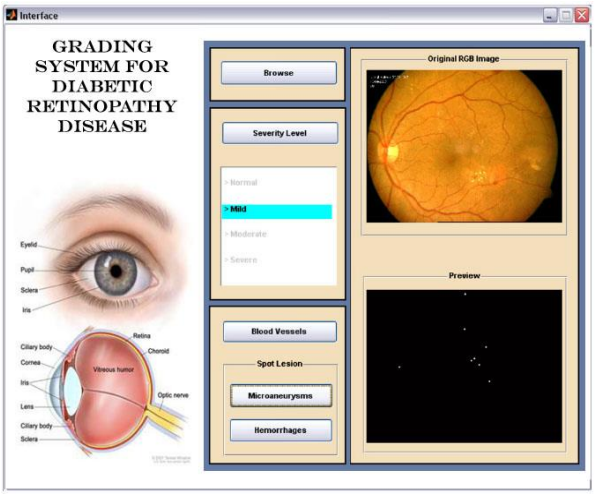


Figure 6. Interface of the developed system

IV. CONCLUSIONS

Algorithms for the extraction of microaneurysms and hemorrhages from fundus images have been presented. An automated decision-support system for DR disease has been designed based on these features. A user-friendly interface has also been presented. The severity level grading of DR has been performed based on the rules which have been reported in the International Clinical Diabetic Retinopathy Disease Severity Scale. The proposed algorithm extracts first the main components of the human retina, i.e. the optic disk, fovea, and tissue for easier segmentation. Then, an efficient algorithm based on h-maxima transformation and multilevel thresholding has been employed for dark spot segmentation. Suitable classification algorithm has also been proposed to classify the dark spots as MAs or HAs using some geometrical criteria. Finally, based on the number and location of MAs and HAs, the severity level has been graded into four scales, i.e. normal, mild, moderate, or severe. Experiments have been conducted using 98 low-quality colour images to evaluate the performance of the developed system. A comparison between the results of the proposed system against the manually-marked images has been done. Based on the experimental results, it is found that the developed system yields remarkable and promising results even though only low-quality images have been used as test images. It is expected that the system would yield better results if it is tested using high-quality images.

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