Automated Segmentation of Hard Exudates Using Dynamic Thresholding to Detect Diabetic Retinopathy in Retinal Photographs

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***Abstract*-Retinal images are in use by ophthalmologists for the clinical analysis and diagnosis of different retinal diseases. The ocular disease known as Diabetic Retinopathy (DR) is a retinal disease that causes microvascular changes in the eye retina. Hard Exudates (HE) a retinal lesion can be seen as bright yellowish spots in colored fundus photograph and as bright white blobs in red free fundus image. The aim of this paper is to propose an automated technique for the identification of HE to help in the diagnosis of DR. The proposed method use dynamic thresholding for the segmentation of HE after calculating intensity based parameters of the input retinal image. Before the segmentation of exudates the Optic Disc (OD) is removed from the image using averaging and morphological operations. A sensitivity of 98.73%, specificity of 98.25% and accuracy 97.62% for HE segmentation is achieved respectively on 1200 images from publically available database MESSIDOR. Compared with state-of-the-art work, proposed automated technique has a reasonable accuracy and can be used as a trustworthy clinical diagnostic tool.**

Index Terms— optic disc; lesions; retina; macula; exudates; micro-aneurysms; arterioles; venules; microvascular; photoreceptors

I. INTRODUCTION

The main body organs that are seriously damaged by diabetes are heart, kidney, liver and eyes, resulting in microvascular and structural irregularities. Diabetic Retinopathy (DR) and its advanced stage Diabetic Macular Edema (DME) are becoming the main cause of blindness in diabetic patients having diabetes mellitus for more than 10 years. The neurosensory retina contains millions of photo-receptors (cones and rods) that are responsible for vision in day and night respectively. DR refers to pathologies of arterioles, capillaries and venules in the retina and later effects due to blocking or leakage of tiny blood vessels. The leakage of lipids from the abnormal blood vessels results in the formation of lesions [1]. The lesions appear on retina are generally categorized as hard and soft exudates.

The Hard Exudates (HE) are composed of lipid-filled macrophages and lipoprotein located in outer retinal layer. The excreted lipids from the surrounding capillaries and microaneurysms become the cause for the development of HE. HE appears as clusters of waxy yellowish spots with distinct boundaries as can be seen in Fig. 1. Soft exudates came into existence due to the blocking of retinal pre-capillary arterioles. They appear as pale yellow-white, apparently white or grayish white dim stains with uncertain and vague boundaries. Soft exudates are also termed as cotton wool spots, found as fluffy lesions in the nerve fiber layer of retina. The retinal ganglion cells are responsible for the transmission of information from photoreceptors (rods and cones) to the brain. The presence of exudates becomes the cause of severe retinal diseases like DR, DME, glaucoma and cataracts.

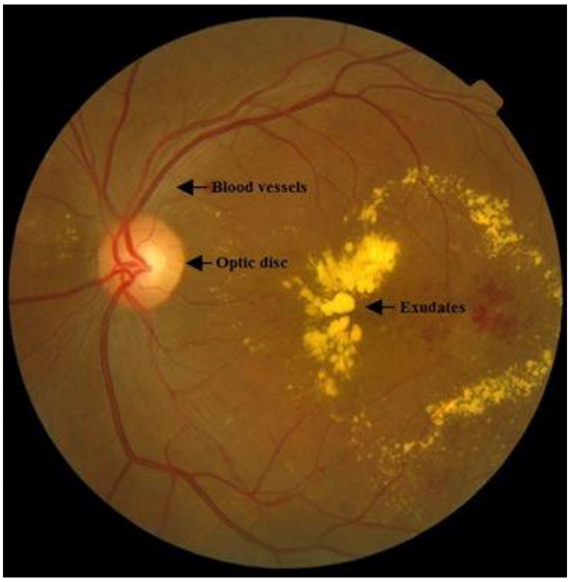

Fig. 1. Colored fundus image having hard exudates

DR occurs due to disorder in retinal blood vessels which cause swelling or leaking of the blood vessels or due to the growth of new abnormal blood vessels on the retina layer. DME is the advanced condition of DR which is associated with the central area of retina known as macula. Macula lutea lies almost in the center of retina; it has approximately a size of 1 disc diameter or 1.5 of millimeter. It is responsible for sharp vision due to more number of cone cells per square millimeter with respect to the surrounding. As the cones are responsible for sharp and color vision in daylight, any lesions found in the region of macula results in a serious stage of DME. A variety of methods are being proposed for the identification and segmentation of exudates to detect the presence of DR, some of these techniques are discussed here.

II. RELATED WORK

Soares et al. in [2] first localizes all possible candidates for exudates using scale-space extrinsic curvature and mean curvature. The real exudate regions are then sorted out using dynamic threshold technique for the segmentation. Guoliang et al. in [3] uses SVM classifier for the extraction of HE. The strategy followed is to take all possible regions that appear as exudates and then refine the result. Giancardo et al. in [4] proposed unsupervised technique for the detection of exudates without the labeling of lesions. A preprocessing is applied for the background estimation, the candidate exudates given a weight and then real exudates are detected. Eswaran et al. in [5] proposed watershed segmentation technique for exudates detection. The input is first preprocessed using averaging filter and contrast adjustment for enhancement of major parts of the fundus image. The extraction of the exudates is done using marker controlled watershed segmentation.

Jaafar et al. in [6] proposed an automated system using adaptive thresholding for the exudates detection. The segmentation is done by calculating the local variation in overall image to get the regions with definite boundaries. Noise is removed from the result using morphological operations. Kande et al. in [7] first preprocesses the image for enhancement and Optic Disc (OD) removal. The enhanced segments of the OD free photograph are extracted using weighted Fuzzy c-Means clustering technique followed by standard FCM clustering. Lim et al. in [8] preprocesses the input using CLAHE and contrast stretching to extract OD and exudates. Internal and external markers are used on the calculated gradient image. Finally watershed transformation is used to get the final resultant image having extracted exudates.

Siddalingaswamy and Prabhu in [9] identify the HE by considering them as bright intensity regions using clustering method. As the intensity variation of the bright spots in front of the background is more distinct in green component of the image so the green channel of colored image is taken for the segmentation of exudates. Eswaran et al. in [10] extracts the exudates based on marker-controlled watershed segmentation. The colored fundus image is taken as input and passes through averaging filter to improve the image quality then contrast adjustment is done by using contrast stretching transformation. Finally gradient magnitude is used for image preprocessing before the watershed transform is applied for segmentation. Kande et al. in [11] use Spatially Weighted Fuzzy C-Means (SWFCM) clustering algorithm to extracts the enhanced segments of the image, exudates in this case. First the identification of exudates is done by preprocessing; removal of OD and exudates segmentation then (SWFCM) clustering method is applied.

Keerthi and Sivaswamy in [12] use multi-space clustering for the exudates segmentation as multi-space clustering use multiple feature space so improved results can be obtained. In clustering two factors the feature space used and distance metric defined on that space are very important. Pixel values in multiple color space are obtained and then labels are defined on this information. Finally the clustering outcomes are fused to get candidate regions while the false regions are suppressed. María García et al. in [13] use MultiLayer Perceptron (MLP) classifier for the detection of HE. After contrast enhancement and segmentation a set of features are extracted. From the extracted features a subset of features is selected that are more important for the problem solution. These selected features are used as an input for MLP classifier.

Soares et al. in [14] used optical fundus image represented in scale space to detect exudates using dynamic thresholding. The curvature is computed for each scale. The extreme locations of the curvature are determined and are tracked up to their initial locations which are found as retinal exudates. Agurto et al. in [15] used multi-scale approach for the detection of exudates in the macula. After removing non-uniform illumination, candidate for exudates are identified using Amplitude-Modulation and Frequency-Modulation (AM-FM). Color, Shape and texture features are also find out for each candidate lesion. These features are then merged with AM-FM features. The abnormality from the macula among candidate lesions is detected using supervised classifier.

Chen et al. in [16] first extracts candidate regions for HE trained a supervised support vector machine (SVM) by using the weighty features of all candidate regions for the exudates classification. Eadgahi and Pourreza in [17] proposed a method for the exudates segmentation by using a mixture of morphological operations. Before the exudates segmentation OD and network of blood vessels is eliminated from the image. Shahin et al. in [18] used supervised learning technique by using Artificial Neural Network (ANN) classifier for the automated classification of DR. The ANN is given with the input of area of exudates, blood vessels, microaneurysms. Ranamuka and Meegama in [19] proposed a fuzzy logic technique for the detection of exudates to diagnosis of DR. It is a two stage process using morphological operation and fuzzy logic. For each pixel of exudate, values in the Red, Green, and Blue (RGB) color space is calculated for a given input set of corresponding RGB channel. The output is then calculated according to the proportion of the exudate area.

María García et al. in [20] automatically detect hard exudates by extracting their features and using them for logistic regression to discriminate HE from background. A MLP and Radial Basis Function (RBF) were also used for the final segmentation of exudates. Gandhi in [21] used SVM classifier to classify the severity level of disease after the exudates detection and feature extraction. Niemeijer et al. in [22] used a hybrid approach for the detection of red lesions in colored fundus image. First pixel classification based system is used to detect all candidates for red lesions. In the second step unique features are added for the candidate regions and classification is done by k-nearest neighbor classifier. Sánchez et al. in [23] proposed an automated technique for the exudates identification based on mixture models. The exudates were separated from the background by dynamic thresholding.

Jaafar et al. in [24] detect red lesions in colored fundus image. After pre-processing of the input image segmentation for the red lesions is done using morphological operations. Rule based classification is then done to find out the actual lesions. Deepak et al. in [25] record the global attributes of image and use them to identify the presence of any abnormality for diagnosis of DR. Verma et al. in [26] proposed a method for the detection the hard exudates by using bounding box and density analysis technique. After the findings of candidates for hemorrhages false positive cases are thrown out with help of feature analysis.

The methods discussed in the literature are supervised as well as unsupervised techniques. Supervised techniques results depends on the training of the system which results in the dependency on the training dataset and time. However some unsupervised learning approaches discussed used segmentation and clustering techniques based on shape and color. We have proposed a method that effectively extracts and remove OD using [27] and calculates a threshold using intensity based parameters of the image. The proposed method gives sound results on the images captured in different lighting conditions as the calculated threshold value totally depends on the intensity based parameters which may vary from image to image, moreover elimination of OD in parallel enhance the system performance.

III. PROPOSED TECHNIQUE

In our proposed methodology identification of HE is done using colored retinal fundus photographs as input. A gray-scale component of image is used for the localization and elimination of OD by applying quality enhancement and morphological operations. Identification of HE is done on the basis of their high intensity values using the green component of image. Segmentation of exudates is done using a calculated threshold value for each individual input image. A flow chart of our proposed methodology is shown in Fig. 2.

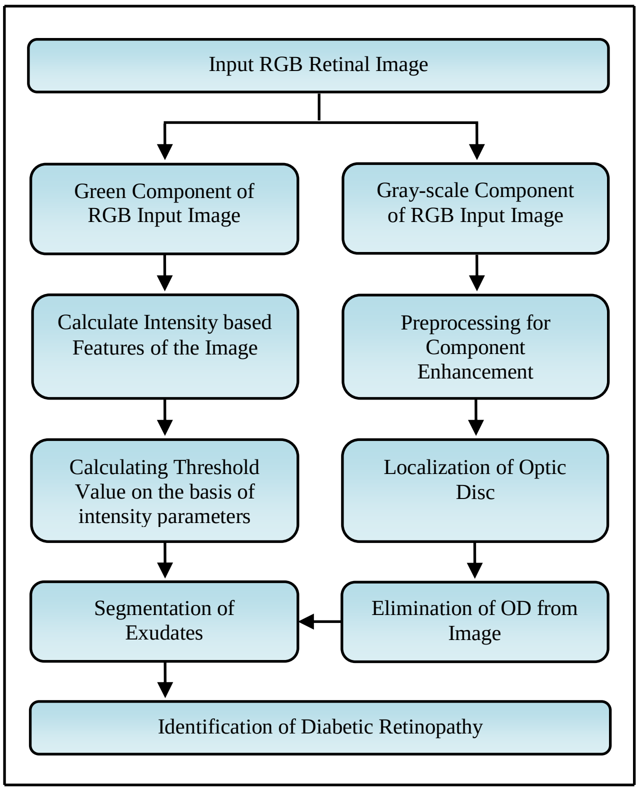

Fig. 2. Flow chart of the proposed technique

A. *Elimination of optic disc*

OD elimination is done before the segmentation of exudates as the presence of OD can results in erroneous detection of exudates. For the OD detection green component of the RGB fundus image is used. The image is gone through a series of preprocessing steps to improve the quality of the image. Image quality is enhanced while using averaging filter, contrast enhancement and adaptive histogram equalization which results in the improvement of Region of Interest (ROI). The foreground components are now become distinct from the background region and can be separated or extracted easily. The OD is detected on the basis of its pixels having high intensity value as compared to the other regions and its comparatively large area as compared to the abnormalities in the overall image. The spotted OD is then subtracted using morphological erosion and dilation operations from the image to get an OD less fundus image. The detailed adopted process for OD detection and elimination is given in [27]. The morphological operations do not disturb the ROI in our case that is HE as the Structuring Element (SE) used for dilation is the same as used for erosion. The overall result after applying erosion followed by dilation would only results in the elimination of the OD.

B. *Calculating intensity based features for the segmentation*

The intensity based properties that include minimum, maximum, arithmetic mean and standard deviation of the entire image are calculated. The calculation for mean and standard deviation done is as follows where μ is for mean and σ is for standard deviation. Arithmetic mean is computed by taking the summation of all pixel values of the entire image and dividing it by the total number of pixels in the whole image as illustrated in (1). Standard deviation is computed by taking the square root of the average of the summation of all pixels value difference from the mean as shown in (2).

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \quad (1)$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\mu)^{\,2}} \quad (2)$$

C. *Segmentation of exudates using dynamic thresholding*

Each fundus image vary in brightness, size and quality, the segmentation for exudates is done by setting a threshold value for each individual image. The premeditated intensity based parameters are used to calculate the threshold value for each individual image. Using the value of these parameters obtained, dynamic thresholding is done for the segmentation of exudates. It is noted while calculating threshold value, as the value of the intensity based parameters go on an increase the threshold value also rises accordingly. So we can say that the threshold value for segmentation is directly proportional to the intensity or brightness of the whole image. If “T” is the calculated threshold value for segmentation and “I” are the intensity based parameters of the input image, the relation can be seen in (3).

$$T \propto I \quad (3)$$

The classifier for the segmentation of exudates assigns a threshold value for each image separately by determining in which illumination range the image fall using minimum, maximum, mean and standard deviation of the image. The segmented exudates can be seen in Fig. 3 as white clusters with defined boundaries having black background. The images used are from the publically available dataset, the image acquisition is done in a controlled environment however the illumination variation exists that is of no deal for our proposed system as the threshold value is directly related to the intensity of the image.

D. Diagnosis of Diabetic Retinopathy

The presence of any lesions like hard exudates indicates the presence of diabetic retinopathy. The results obtained after the segmentation of exudates as seen in Fig. 3 can be used by ophthalmologists to ease the diagnostic process. If the white blobs appear in the final image it indicates the presence of lesions otherwise the case is treated as normal.

IV. EXPERIMENTAL RESULTS & CONCLUSION

Messidor database comprising 1200 images is used for the results and comparison [28]. The images are divided into three sets containing 400 images and then each set is sub-divided into 4 parts. An excel file is available with each set having medical findings mentioned against each image for the testing purpose. Messidor provides a general distribution of images into three groups normal images: 971, Non-Clinically Significant Macular Edema (Non-CSME): 75, and Clinically Significant Macular Edema (CSME): 154. Total number of database citations in six years from 2008-2013 are 189. Our methodology is practically checked on these 1200 colored fundus retinal images having a wide variety of different abnormalities, brightness and varying dimensions of the image. Some results of our proposed technique can be seen in Fig. 3 where the colored fundus image is taken as input and after the removal of OD the exudates are detected. The exudates are seen as bright spots in front of a black background. The presence of exudates is an alarm for the existence of diabetic retinopathy. In Fig. 3 column (a) comprises the colored fundus images having HE present in them, the column (b) is the resultant image obtained after the removal of OD from the input image and finally the column (c) contains images obtained after the segmentation for exudates.

To assess the true efficiency of our proposed technique the results are evaluated on three parameters here sensitivity, specificity and accuracy. Moreover these results are then compared with the previously existing techniques to estimate the precision parameter. The sensitivity, specificity and accuracy are computed using (4), (5) and (6) respectively.

$$\text{Sensitivity} = TP / (TP + FN) \quad (4)$$
$$\text{Specificity} = TN / (TN + FP) \quad (5)$$
$$\text{Accuracy} = (TP + TN) / (TP + FN + TN + FP) \quad (6)$$

Where TP, TN, FP, FN denotes true positive, true negative, false positive and false negative respectively.

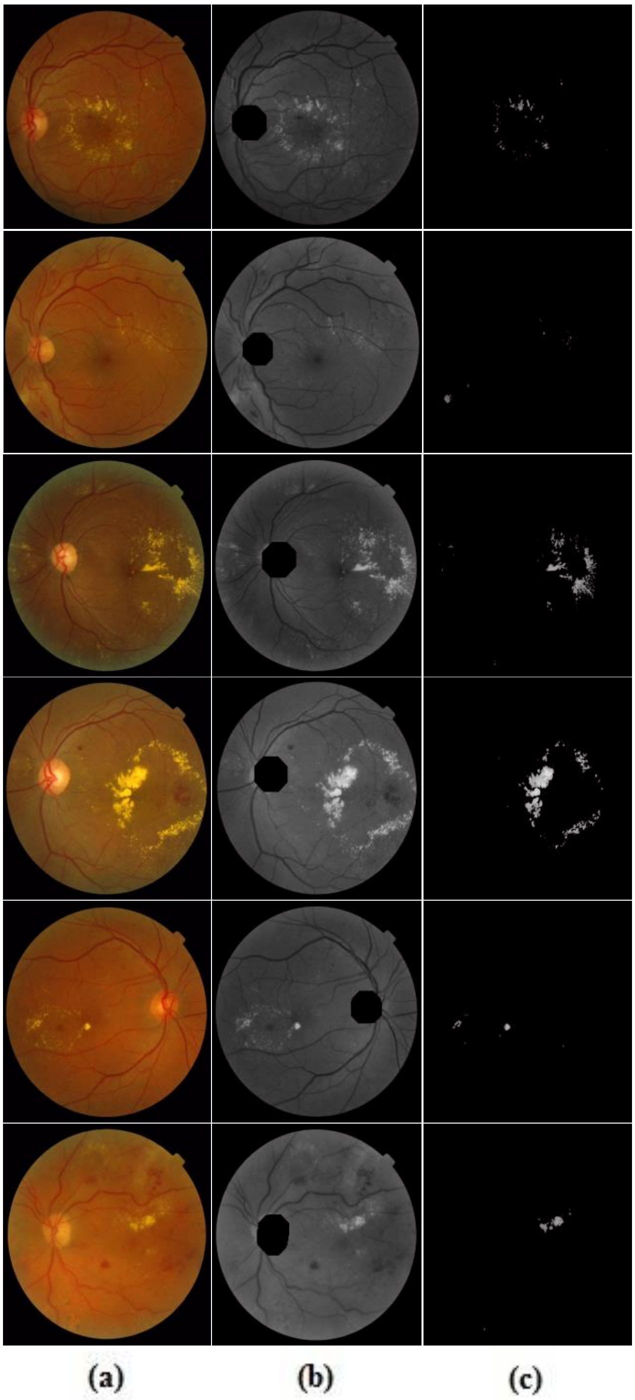

Fig. 3. Column a): colored fundus image; b): resultant image after optic disc elimination; c): segmented exudates

A comparison of results obtained by our proposed system with the previously used techniques can be seen in table I. The comparison shows that the suggested technique delivers better results as compared to the existing techniques for exudates segmentation. The comparison of our system is done with those techniques that have used the same database for their result evaluation.

TABLE I. PERFORMANCE COMPARISON OF PROPOSED TECHNIQUE WITH PREVIOUSLY EXISTED TECHNIQUE

Technique	Sensitivity	Specificity	Accuracy
Giancardo et al. [4]	-	-	89%
Deepak et al. [25]	100%	97%	81%
Proposed Technique	98.73%	98.25%	97.62%

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