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Original Article

Automatic detection of retinal exudates in fundus images of diabetic retinopathy patients

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Abstract

Introduction: Diabetic retinopathy (DR) is the most frequent microvascular complication of diabetes and can lead to several retinal abnormalities including microaneurysms, exudates, dot and blot hemorrhages, and cotton wool spots. Automated early detection of these abnormalities could limit the severity of the disease and assist ophthalmologists in investigating and treating the disease more efficiently. Segmentation of retinal image features provides the basis for automated assessment. In this study, exudates lesion on retinopathy retinal images was segmented by different image processing techniques. The objective of this study is detection of the exudates regions on retinal images of retinopathy patients by different image processing techniques.

Methods: A total of 30 color images from retinopathy patients were selected for this study. The images were taken by Topcon TRC-50 IX mydriatic camera and saves with TIFF format with a resolution of 500 × 752 pixels. The morphological function was applied on intensity components of hue saturation intensity (HSI) space. To detect the exudates regions, thresholding was performed on all images and the exudates region was segmented. To optimize the detection efficiency, the binary morphological functions were applied. Finally, the exudates regions were quantified and evaluated for further statistical purposes.

Results: The average of sensitivity of 76%, specificity of 98%, and accuracy of 97% was obtained.

Conclusion: The results showed that our approach can identify the exudate regions in retinopathy images.

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Introduction

Diabetic retinopathy (DR) is the most frequent microvascular complication of diabetes and the most common cause of blindness in the working population of the world. Early detection of DR is critical for successful treatment.[1] The common way for diagnosis is the evaluation of retinal images by ophthalmologists. In addition, there are many signs of retinopathy on retinal images to help the early detection of disease. One of these signs is exudates that appear differently in a yellowish or white color with varying sizes, shape, and locations. Exudates are the protein deposits. The size and location of exudates are important information for an ophthalmologist to show the severity of disease.[2]

An automatic exudate detection system would be useful to detect and distinguish DR

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in retinal images of screening programs.[3] Many studies have been performed for exudate detection based on variety of techniques. Sharma et al.,[4] anticipated detection of exudates with the help of contextual clustering and radial basis function. Wisaeng et al.[5] segmented the exudates using the support vector machine classifiers. Their value of sensitivity, specificity, and accuracy were 94.5, 89.5, and 92.1 percent respectively. In another study, exudates detected using a fuzzy clustering technique with 92.0% sensitivity and 91.5% specificity.[2] Osareh et al.[6] uses image-based criteria for assessing the diagnostic accuracy of an exudate detection technique.

In this study, we proposed a fast method for detecting exudates in retinal fundus images by combining available morphological algorithm.

Methods

Digital retinal images were obtained using Topcon TRC-50 IX mydriatic retinal camera at Nikokary eye hospital, Tabriz, Iran. The size of color images was 500 × 752 pixels resolution with 24 bit in tiff format files. The research protocol of this study was approved by Ethics and Research committee of TUMS (Code number 90/2-4/3).

In the beginning, before the detection of abnormalities and features in retinal image the intensity components of hue saturation intensity (HSI) space was extracted from images, then a median filter with a 3 × 3 window size was applied for reducing the image noise. We used this component because the exudates have good contrast with background.[7]

Afterward a gray scale top-hat operator[8] was applied to enhance the bright lesion such as exudates. The morphological top-hat transformation of an image, denoted T, is defined as follows:

$$T = f - (f \circ b)$$

Where, f is the input image, $f \circ b$ is morphological gray scale opening of f by b, and b is the structuring element function.

However for applying the top-hat operator on image, the intensity component of image was morphologically opened to remove small bright details while leaving the larger bright features.

A linear structure element with a straight line with length of 11 pixels at an orientation of θ was used. The length is chosen to be just greater than the length of the largest feature to be segmented from the image.[9] Empirically, it was found that an 11 pixels linear structuring element at eight orientations gave the best compromise to segment the larger exudates.[9] The opened image contained vessel sections with no small bright lesion. Figure 1 (A and B) shows a result of opening operator on intensity component of HSI space. The top-hat operation was completed by subtracting the opened image from the original one.[8]

The difference highlights bright lesion (such as exudates) and suppress linear vascular structures (Figure 1, C).

Then, to emphasize the exudates region the magnitude of the gradient, denote T_G, T_G, was calculated using a "derivative of a Gaussian filter" (Figure 1, D). For this purpose, the top-hat image, T, was convolved with a derivative of a Gaussian along rows and columns.

$$T_G = \sqrt{T_{Gx}^2 + T_{Gy}^2}$$

Where, G is two-dimensional Gaussian function, T_{Gx} and T_{Gy} are the gradient vectors of input images:

$$G = Ae^{\frac{-(x-x_0)^2}{2\sigma_x^2} + \frac{-(y-y_0)^2}{2\sigma_y^2}}$$

$$T_{Gx} = \left(T \times \frac{dG}{dx}\right)$$

$$T_{Gy} = \left(T \times \frac{dG}{dy}\right)$$

x_0 and y_0 are the center of peak in the Gaussian function. A is amplitude and σ_x, σ_y are the standard deviation along row and column. The size of this filter was selected 13 × 13 for the standard deviation of σ_x, = σ_y = 1.5 experimentally.

Due to the presence of other bright features in retinal images and due to natural variations in retinal reflectivity, most of the bright features are not exudates. Therefore to produce binary image for separating exudates from other features, one threshold operator was applied on the result image (Figure 1, E).[8] We used P^{th} percentile of the histogram to separate these difference.

Because of similarity of properties of optic disk to exudate, this feature was appeared in binary image, so the optic disc was removed by morphological processing and characterized by the largest high contrast among circular shape areas in according to Sopharak et al. study.[10]

To eliminate small dots, smooth contours of exudates and eliminates small holes a binary closing operator afterward a binary opening operator were applied (Figure 1, F and G). A flat disc-shaped structuring element with a fixed radius of two was used.

To determine the area of each exudate lesion within the image, the number of white pixels which connected together was counted in binary image. Furthermore, to determine concern pixels of exudates, all white pixels in binary image was divided by whole pixels of retinal image. Finally, the borders of the exudates regions predicted by morphologic operators superimposed on original image (Figure 1, H). This type of presentation will enable clinicians to identify pathology more quickly and quantify.

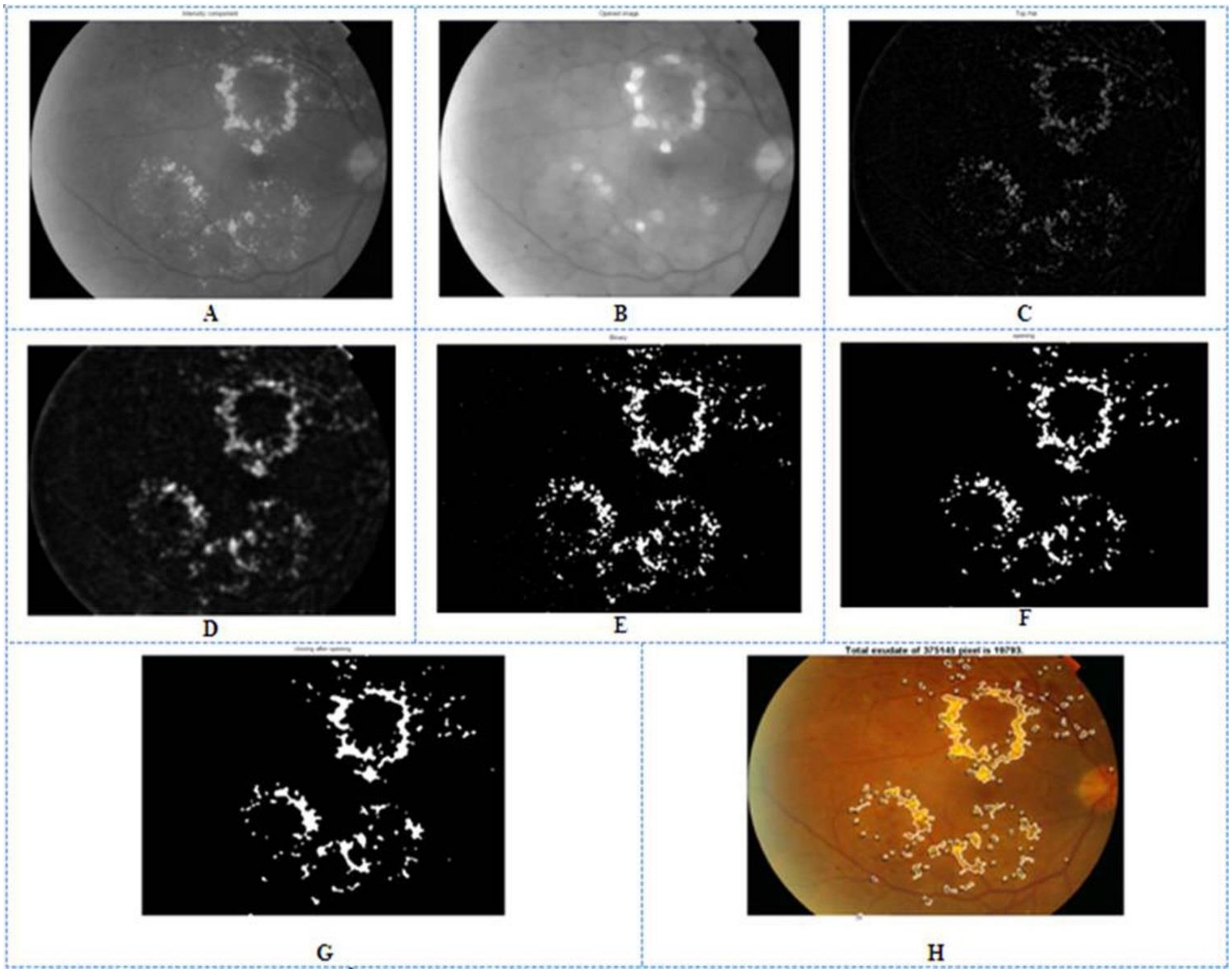

Figure 1. Exudate detection of one sample: (A) The intensity component of original image, (B) the opened image, (C) the result of top-hat operation, (D) the result of a derivative of a Gaussian filter along rows and columns, (E) thresholded image, (F) binary opened image, (G) binary closed image, (H) the borders of the exudates superimposed on original image

To evaluate current algorithm, the exudates of retinal images were segmented and compared pixel by pixel with ophthalmologist's outline of the exudates as standard regions, then sensitivity, specificity, and accuracy were calculated.

The sensitivity is the proportion of exudate pixels which are positively detected, and specificity is the proportion of non-exudate pixels which are negatively detected,

$$\text{Sensivity} = \frac{\text{TP}}{\text{TP+FN}}$$

$$\text{Sensivity} = \frac{\text{TN}}{\text{TN+FP}}$$

Accuracy is the overall per-pixel success rate of the classifier.

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+FP+TN+FN}}$$

Results

Figure 2 (A and B) shows six samples of retinal images with the exudate segmentation results which were overlaid on their original image.

Each row represents an individual patient's data including original retinal image in the first column and predicted borders of the exudates regions which superimposed on original images, were shown in the second column.

As it can be shown in figure 2, this technique has been successful in detection of exudates regions.

The average of sensitivity, specificity, and accuracy of the exudate detection were 76, 98, and 98 percent, respectively. Furthermore, the operating time to segment and calculate the area of exudate lesion within the image was < 3 seconds.

Discussion

In this study, we have utilized morphological operations for segmentation of exudates from DR retinal images. Our results showed that current technique can identify the exudate regions in retinopathy images with high accuracy.

Based on study of Sopharak et al., the sensitivity of image segmentation algorithms equal or greater than 60.0% increased the efficiency of screening for DR patients. While the results of our algorithm showed higher performance in comparison to the above-mentioned value.[10]

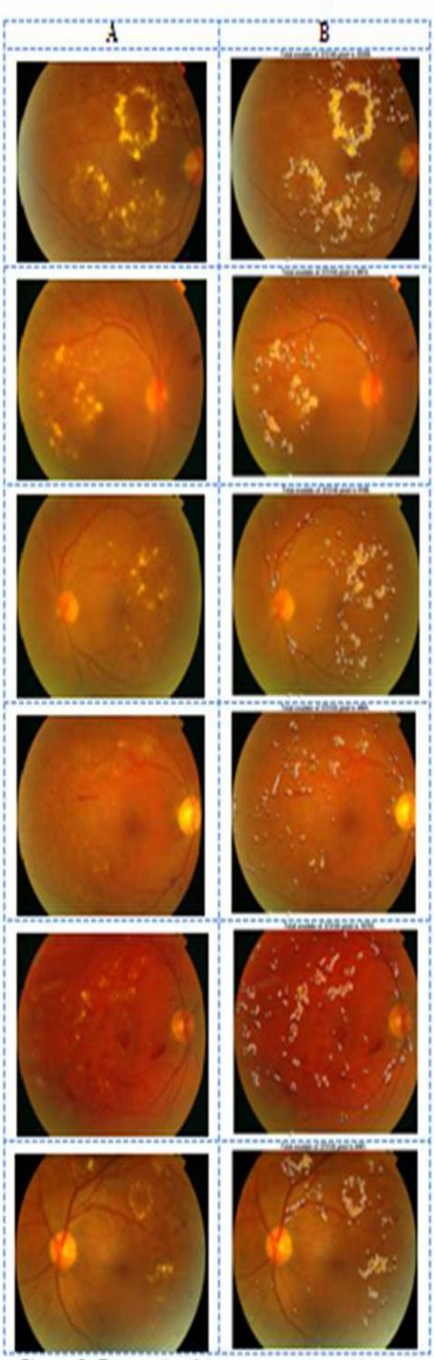

Figure 2. The results of image processing which was performed in the current study: (A) Six original images, (B) borders of the exudates regions predicted by morphologic operators superimposed on images on intensity component of hue saturation intensity (HSI)

In a similar study by Fleming et al.,[11] they reported the sensitivity of 95.0% and the specificity of 84.6% for their applied method including morphological segmentation and dynamic thresholding using maximum likelihood estimation. The sensitivity of our technique was relatively lower than their results while our specificity was considerably higher than their reported value. We should note here that our lower sensitivity could be attributed to the difference in the thresholding value used in our algorithm.

Recently, Ranamuka and Meegama[7] reported a respective sensitivity and a specificity of 75.4% and 99.9% in detecting hard exudates. Their technique was based on morphological image processing and fuzzy logic to detect hard exudates from DR retinal images. Our results were in good agreement with their results.

Comparing to other recent automatic methods available in the literature,[7,10,11,12] our proposed method can obtain acceptable exudates detection tool in term of sensitivity and specificity.

There are many variables that compromise fundus photography of the human eye. Among the independent variables, the most important ones are the opacity of vitreous fluid, pigmentation of the fundus, hemorrhage, presence of vasculature abnormality, age, and color of the skin.[1,11,13] Dependent variables such as field of view and power of flashes are the other contributors to imaging. Moreover, it is a complex task to threshold the images and assigns appropriate signal levels for extracting the hard exudate areas. By considering such large number of variables, an effective method to overcome this obstacle is to develop a large databank of fundus images whose exudate areas have been positively identified by an expert clinician. Using such databank, image parameters and corresponding threshold levels can be assigned by simple comparison metrics.

Conclusion

Our method can be used to help ophthalmologists during exudates screenings to detect symptoms faster and efficiently. Furthermore, this method can be a preliminary diagnostic tool or a decision support application for expert ophthalmologists. We suggest applying other thresholding techniques on our proposed algorithm to improve its performance.

Conflict of Interests

Authors have no conflict of interest.

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