SOCIETY FOR SCIENCE AND EDUCATION
UNITED KINGDOM

JBEMi JOURNAL OF BIOMEDICAL ENGINEERING AND MEDICAL IMAGING

ISSN: 2055-1266
VOLUME 2 ISSUE 1

Segmentation and Measurement of Exudates in Fundus Images of the Retina for Detection of Retinal Disease

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ABSTRACT

Retinal diseases are asymptomatic in nature with the significant effect of vision loss. With the growing number of retinopathy cases each year there is a requirement of the evaluation of large amount of database. This has led to the development of numerous automated and semi-automated evaluation methods to track the retinal diseases. In this study, a simpler automated method is developed to diagnose retinal disease as far as exudates are concerned. Previously used segmentation methods do not generate very satisfactory results mainly because the composition of exudates which are degenerated regions in retinal fundus image is non homogeneous. Therefore an alternative method for segmentation is developed to use the homogeneity of healthy regions than degenerated regions. The developed technique initially separates the healthy regions like blood vessels and optic disc from the retinal fundus images and classifies as healthy. Further the dynamic region growing method is employed for the segmentation of exudates in the images containing diabetic retinal disease. The technique developed is examined on various retinal images and the outcomes reveal that the presented technique performs better than the previous proposed methods for the segmentation of exudates.

Keywords: Retinal Fundus Images; Optic Disc; Blood Vessels; Automated Segmentation of Exudates.

1 Introduction

One of the most significant complications causing severe damages to the retina is retinopathy. Subsequently it causes visual loss and blindness in some cases if medical treatment is not given on time. Diabetic retinopathy is diagnosed by structural alterations in the retina, which can be exploited in the image processing for the automated detection and diagnosis of disease. As the disease develops over a period of time, continuous monitoring is necessary to diagnose the early symptoms so that timely effective treatment can be taken [1-3]. Manual segmentation of retinal images is quite difficult and the clinician may make mistakes during the process [3,5]. Also this is a very time consuming process. Therefore an automated system for the segmentation of disease could diminish the workload of the experts. The degenerations in retinal fundus images are segmented and then the disease can be measured by the system. After the automatic segmentation of lesion if further analysis is required it is

DOI: 10.14738/jbemi.21.987
Publication Date: 24th February 2015
URL: http://dx.doi.org/10.14738/jbemi. 21.987

examined by the expert. Grade of the segmentation carried out is determined by the type and quality of the acquired image, experience and expertise of the clinician.

Recent studies have shown that retinal diseases like diabetic retinopathy can be analyzed from fundus images of the retina [4,6,10]. Segmentation and measurement of the development of different degenerations associated with this disease like microaneurysms (MA), Cotton wool spots (CWS), hard exudates (HE) etc. is quite difficult due to their irregular structural variations. Currently numerous semi-automated and automated methods are being used for the lesions segmentation associated with retinal diseases.

Automated assessment of pathologies related to retina requires the accurate segmentation landmarks such as of optic disc and blood vessels from the retinal fundus image, so that lesions can be extracted from the image successfully. Gracia et al. proposed a radial basis function classifier to detect HE and also various other features were extracted from retinal fundus image [14]. The section which suitably distinguished exudates and background of the retinal fundus image was chosen by applying logistic regression method prior to the application of normalization and segmentation of candidate areas. Post-processing techniques are applied on the retinal fundus images to eliminate the noisy regions. Other studies employ preprocessing methods like shade correction, normalization and image enhancement on retinal fundus images. Further they apply diameter closing and an automatic threshold scheme for detection of candidate portions which are categorized as unhealthy and healthy [11].

Degenerations associated with retinal diseases are non-uniform and intricate in shapes. Thus, efficient segmentation of these ill shaped structures requires complicated and expensive methods. On the contrary, healthy compositions of retinal fundus images have uniform shapes, and segmentation of these uniform shapes is much easier as compared to the non-uniform shapes. In the previous studies, numerous techniques have been proposed for the precise segmentation of lesions associated with retinal fundus images but are not very effective in proper and accurate segmentation of various retinal pathological regions because of the irregular and non-uniform patterns and complex structures of the lesions. In this study, a converse technique is developed for segmentation and quantification of exudates. This method is simple as compared to earlier methods as it utilizes the background retinal image for measuring exudates for the detection of retinal disease. The developed method is quite efficient, less expensive and promising as compared to the earlier techniques developed.

The paper is structured as follows. A brief of the previous segmentation techniques in literature for detecting various lesions in retinal fundus images are presented in Section 2. A brief outline of techniques used in the segmentation such as location of optic disc, determining background image and elimination of blood vessels are presented in Section 3. Section 3 also explains the dynamic region growing and threshold based technique with background image for segmentation of exudates associated with retinal disease. Performance estimation measures are explained in Section 4. The results of performance measures are presented and discussed in Section 5. The conclusions and future work are presented in Section 6.

2 Background

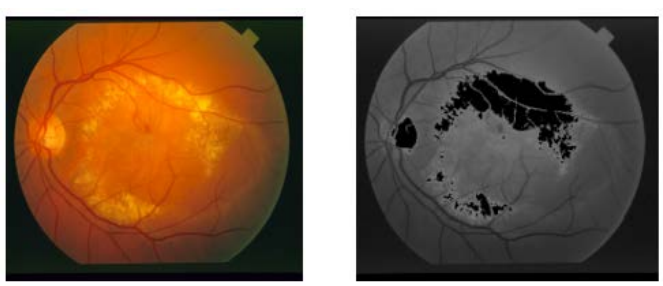
With the idea of researchers designing automated system for detection of retinal disease numerous techniques in literature exist for the segmentation of exudates, location of optic disc, segmentation and elimination of blood vessels to screen and monitor retinal disease in retinal fundus images [8,13,18]. Most of previous segmentation methods developed are dependent on matched filters, image thresholding, edge detection, matched filters and tracking models [9,15,22]. Pattern recognition method, automatic model based detection, texture analysis, and mathematical morphology based methods have also been proposed for the detection of degenerations in retinal images. Few of these methods work on location and detection of landmark structures in retinal fundus images [19,23]. These methods mainly concentrate on segmentation and detection of only one type of landmark structure like blood vessels or optic disc [23–25]. Also few techniques detect more than one features and lesions in retinal fundus images [1,22,28]. Sinthanayothin et al. employed a multi-layer perceptron neural net in which inputs are acquired from a principal component analysis method for edge detection in retinal fundus images for optic disc detection [29]. Various techniques are also presented in literature for detection of optic disc, fovea and other landmark structures in retinal fundus images [19,23]. In addition, Walter et al., Quellec et al., Xu et al., established automated techniques for detection of MA's [11,16,30].

Numerous other approaches were presented for automatic segmentation of degenerations associated with retinal disease [8,12,15]. Even though number of techniques has been developed in this domain, those are restricted by one or other following limitations. At the initial step, clinician is required to determine the region of interest and the techniques were also not entirely automated. Differing image conditions may produce imperfect and unacceptable kinds of segmentations. Also, most of the earlier segmentation techniques if applied to detect one type of lesion it overlaps with other degenerations related to retinal diseases. Lastly, various segmentation algorithms in proposed methods need huge computational efforts and time.

3 Methods Used in the Segmentation of Exudates

Number of methods has been employed for the automatic segmentation of diabetic retinopathy such as vessel elimination methods, background image extraction method and Optic disc detection methods. In such methods, firstly images are transformed into 2^8 levels gray value retinal fundus images and background image of healthy portions is separated from the converted gray value retinal fundus image.

Our method first generates the background reference image as shown in figure1.



(a) (b)

Figure 1: (a) Original Image (b) Reference Background Image

After the segmentation of retinal fundus image optic disc detection is carried out for location and elimination of optic disc region. To discard the blood vessel shapes from the resulting segmented retinal fundus image vessel elimination method is applied.

Retinal image is thus divided based on low and high intensity regions and the dynamic threshold value is used to segment the intensity with higher value and high contrast lesions in the retinal fundus image. So, the clear and bright regions are separated by the means of dynamic thresholding and converse segmentation method. This method uses dynamic thresholding method and conforms itself to intensity variations across the entire retinal fundus image and produces better results than the earlier methods used in the literature. First the method segments the healthy structures in the image and then conversely segments unhealthy portions from the retinal fundus images. The flow diagram of the above processes is shown in figure 2.

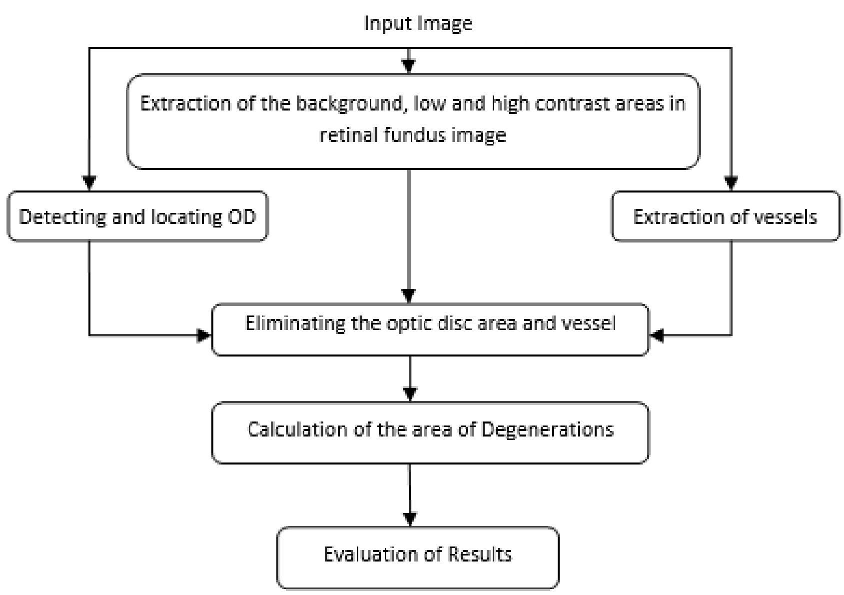


Figure 2: The Flow Diagram of the Algorithm Proposed

Steps in the automatic segmentation technique for detecting exudates are as the following:

- Extraction of the reference background image of healthy regions in the retinal fundus image.
- Identification and segmentation of high and low contrast areas in the image.
- Location and detection of optic disc.
- Extraction of vessels
- Elimination of vessels and optic disc region.
- Calculation of the area of anatomic structures and lesions in the image.
- Generating statistical parameters to objectively evaluate the algorithm.

3.1 Steps for Locating and Eliminating the Optic Disc

Optic disc is one of anatomical structures in retinal images. Thus the location and detection of optic disc is crucial in analysis and quantification procedure of degenerations in retinal fundus images. The distinct properties of optic disc like high intensity; circular geometric structure etc. can be utilized in the detection. In the literature, various methods are used to segment [13,32] and detect [19,23,26] optic disc in retinal images. In this method transformed sobel filter given by Equation (1), it makes edges in the image clearer.

$$\mathrm{Img}_{\mathrm{fil(i,j)}} = \frac{\sum_{k=1}^{n} \mathrm{abs[img\_ver\_fil(i+k,j)]+abs[img\_hori\_fil(i,j+k)]}}{n} \quad (1)$$

Where k stands for the distance shown in figure 3., (i, j) depicts the value for current pixel and $\mathrm{Img\_fil}(i, j)$ represents the filtered image. $\mathrm{img\_ver\_fil}[(i + k, j)]$ and $\mathrm{abs}[\mathrm{img\_hori\_fil}(i, j + k)]$ represent vertical and horizontal sobel operations.

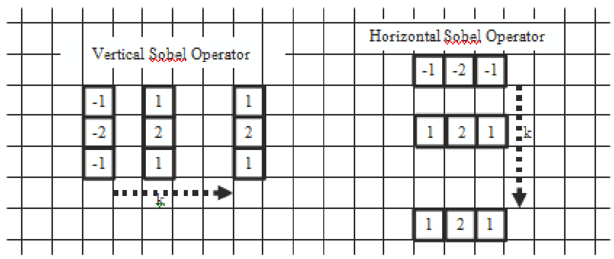


Figure 3: Transformed vertical and horizontal sobel filters

In the given Equation (1), to obtain the blood vessel boundaries clearly in the resultant image n is set to 3 so that edges of the optic disc could be applied to detect the position of optic disc. In order to utilize the distinctive features of the vessels in the optic disc region the histogram of the processed image is computed and the extreme values of the horizontal and vertical histogram of the processed image around optic disc are identified to detect the optic disc. The blue lines on the figure 4 around the optic disc determine the location of optic disc.

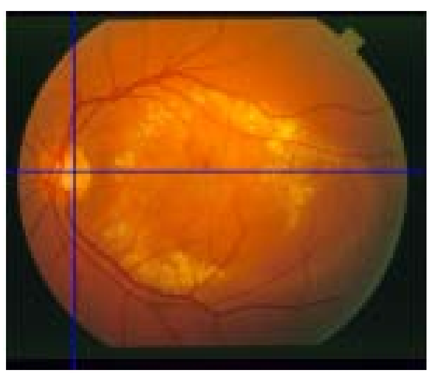


Figure 4: Identification of location of optic disc

The image is processed using transformed sobel filter and high contrast regions are determined using the reference background image. Then these high contrast regions are eliminated from the processed image by examining the region surrounding the present pixel value. If the eighty percent of the region around optic disc shows high intensity values, the pixels are discarded. Small fragments of the vessel and noisy parts are also discarded from the filtered image.

Optic disc region may also be detected as retinal degeneration portions and thus degenerations cannot be measured correctly. Therefore optic disc region must be discarded from the resulting segmented image. Pixels around the optic disc are discarded by taking the average diameter of the optic disc.

3.2 Elimination of Blood Vessels in Retinal Images

A large number of techniques are presented in literature for detection and segmentation of vessels in fundus images [9,21,24,27]. Retinal images consist of a large variety of vessel structures and these should be discarded properly to enhance the precision of the resulting segmented image containing exudates.

The intensity value of each pixel is examined and if it is found within the required interval with respect to the reference background image, it is taken as the blood vessel and taken as the healthy portion or else classified as unhealthy. The interval changes dynamically according to the reference background image. Consequently, all blood vessel shapes are eliminated for segmenting exudates successfully. Vessels are segmented using the method proposed by Kose et al. [31].

3.3 Modified Dynamic Region Growing Technique with Reference Image

Degenerations due to retinal disease may occur over the entire retinal fundus image and the average intensity may vary across the whole retinal fundus image. The segmentation method should tolerate these changes to segment the images efficiently. The difference of the reference image and the average of the pixels segmented is successfully measured by applying Equation (2).

$$\mathrm{Img(i,j)\_seg} = (\text{Healthy if } \left|\mathrm{Img}_{\mathrm{org(i,j)}} - \mu + \alpha_{\mathrm{l,u}}\left[\mathrm{Img}_{\mathrm{bgnd(i,j)}} - \mu\right] - \beta\left[\mu - \mathrm{Img}_{\mathrm{org(i,j)}}\right]\right| \leq \Delta, \text{ unhealthy if otherwise or vessel} \quad (2)$$

Where

- $\mathrm{Img(i,j)\_seg}$ are the segmentation results,
- $\mathrm{Img\_org(i,j)}$ depicts the intensity value of the present pixel,
- μ represents the average value of the segmented pixels,
- Δ Represent the reference threshold value which is approximately adjusted to 8.8.
- β Represent average value correction constant, which is approximately adjusted to 0.49.
- $\mathrm{Img\_bgnd(i,j)}$ is the background image and α is the background toleration constant.

$\left|\mathrm{Img\_org(i,j)} - \mu + \alpha_{\mathrm{l,u}}[\mathrm{Img\_bgnd(i,j)} - \mu] - \beta[\mu - \mathrm{Img\_org(i,j)}]\right| \leq \Delta$ is used as

$$-\Delta + \mu - \alpha_{\mathrm{l}}\,[\mathrm{Img\_bgnd(i,j)} - \mu] < Img\_org(i,j) < \Delta + \mu - \alpha_{\mathrm{u}}\,[\mathrm{Img\_bgnd(i,j)} - \mu] \quad (3)$$

Thus $\alpha_{\mathrm{l,u}}$ contain maximum and minimum cut of values which are constants and the values are set experimentally to 0.93 and 0.49.

Thus intensity variations over the entire retinal image are measured and degenerations across the retinal fundus image are segmented efficiently. Modified dynamic region growing technique used adjusts by its very nature to the varying intensity conditions and efficiently segment exudates over the whole retinal fundus image without needing any requirement of the clinician. One of the tested segmented images is shown in figure 5. Dynamic region growing method achieves best segmentation performance as far as previous region growing methods are concerned.

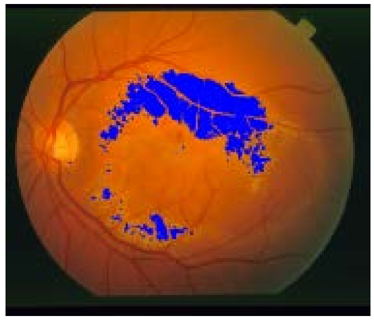


Figure 5: Final Segmented image containing exudates

3.4 Segmentation Method for Detecting Dark Lesions

The approach is to segment the region with lower intensity value as compared to the background image intensity value. Thus the low intensity regions consist of blood vessels and low contrast degenerations. Further the segmentation of vessel technique utilized in [29] is applied to eliminate the vessels. The areas which are left prior to the segmentation of vessels are the low contrast degenerations and considered as the unhealthy portion of the retinal image. Threshold constant is adjusted just below the intensity value of the reference background image. Therefore the pixels whose intensity value is lower than the above adjusted threshold constant is categorized unhealthy portion prior to the elimination of vessels. These pixels are set to blue in the resulting image.

4 Performance Evaluation Measures Used

In the medical field, the eye specialists have to handle huge amount of retinal fundus images. Therefore, an automated segmentation and quantification technique may facilitate the experts to analyze the images more speedily. The presented technique automatically segments exudates in retinal fundus images found in the progression of retinal disease.

As mentioned earlier, experiments prove that manually segmenting and measuring retinal degenerations are somewhat complex and difficult, and the clinician may simply make faults during the process of segmentation [1–3]. Nature of segmentation carried out also varies based on the quality of the retinal fundus image and knowledge of the clinician. In this proposed approach, three performance measures are used to obtain the effectiveness of segmentation method used.

Tp - true positive, Tn - true negative, Fn - false negative and Fp - false positive.

Sensitivity and specificity are also mainly used mathematical performance measures to present the results in more comprehensible form. Sensitivity is the fraction of true positives rightly categorized by the technique. Specificity is the fraction of the true negatives rightly categorized by the technique. Sensitivity and specificity measures are computed by applying Equation (4) and (5).

$$\text{Sensitivity} = \frac{\text{Tp}}{\text{Tp+Fn}} \quad (4)$$

$$\text{Specificity} = \frac{\text{Tn}}{\text{Tn+Fp}} \quad (5)$$

In this proposed application, a simpler technique is used to determine the area and magnitude of retinal degenerations based on Equation (6).

$$\mathrm{Deg\_area} = \sum_{i=1}^{M} \sum_{j=1}^{N} \{\mathrm{Pixel}(i,j)\} . \mathrm{seg} \quad (6)$$

Where Deg_area is the degenerated area in the retina. Pixel(i,j) Represent the pixels in the region as unhealthy portion, is adjusted to 1, and seg represents segmentation outcomes. In this method, seg is set to 1 for pixels which are already segmented and 0 for other remaining pixels.

5 Results

In the study carried out, a total of 128 retinal fundus images with 760 × 570 pixels resolution in various varieties as shown in Table 1 were utilized to estimate the effectiveness of the method presented. The retinal images were acquired from digital retinal fundus camera in SGHS hospital located in Sohana, Punjab, India. A number of the retinal fundus images, including 57 images with apparent optic disc, were also utilized to test optic disc location and identification performance of the system. Figure 5 shows the tested retinal fundus image with HE and its automatic segmentation results.

To present the variations in the segmentation of retinal disease, distributions of the degenerated portions in retinal images are shown in Table1. It is observed that most of the retinal degenerations are distributed over the entire retinal fundus image.

Table 1: Distributions of Hard Exudates in Retinal Fundus Images.

Distributions of HE in Retinal Images	No. of Images	In percent
HE spread around Macula	38	29.68
HE spread around whole image	90	70.3
Total no. of Images	128	100

In order to evaluate the efficiency of the method proposed, developed system is tested on retinal fundus images with varying sizes of HE namely small, medium and large. The basic step in our method is to locate the position and detect the optic disc in numerous types of cases. Thus, the developed database for measuring the performance of the system in optic disc localization and detection comprises of all types of retinal fundus images. On the contrary, images with retinal disease are utilized for the quantification of the HE segmentation performance.

In the optic disk identification and location, mainly the outcomes are obtained for the retinal images with the retinal disease. Results for identification of optic disc and elimination of optic disc region are given in Table 2. The results depict about on an average 96.1% of the optic disc on the images with varying sizes of degeneration, are identified efficiently.

Table 2: Identification and Location of optic disc (OD)

OD No. of Images	Identification and Location of OD		
	Precisely	Roughly	Wrongly
57 Images with clear OD	42	13	2
71 Images with non-clear OD	54	14	3
Total %age	96.1% Located correctly		

To evaluate the performance of the segmentation technique used for hard exudates sensitivity and specificity parameters are measured, and their results are shown in Table 3. In all tests carried out all over the paper, the threshold constant was kept same and parameters mentioned above are used to generate consistent and comparable results. Therefore, minute under and over segmentations are seen in few of the test cases. However the developed technique is still very promising in detection and segmentation of HE.

Table 3: Performance Measures for the Detection of Hard Exudates.

	Hard Exudates	
	Sensitivity	**Specificity**
Images with small lesions	0.981	0.986
Images with medium lesions	0.972	0.998
Images with large lesions	0.984	0.998
Average	0.979	0.994

In the previous work, numerous techniques are implemented for segmentation of retinal disease in retinal fundus images [2,13,15,22,29]. The evaluation of the technique on the database images with hard exudates is about 98.65% which is better than the previous techniques proposed in the literature. The results in Table 3 show that the modified dynamic region growing technique provides a superior performance among other segmentation techniques mentioned in the study.

6 Conclusion

In the literature several techniques produce various performance parameters in the segmentation of degenerations associated with retinal disease and optic disc detection. The methods employed with expert requirement produce approximately 91% of segmentation precision [2,7,8,15,17]. On the contrary, OD localization performance parameter values of these techniques are also around 95% [20,26]

In order to segment exudates dynamic region growing method is used. The developed technique, tested on 128 retinal fundus images, showed higher precision in segmentation than the other techniques. The entire interpretation of a particular retinal fundus image was carried out in around 7 seconds without any expert involvement. The method locates and detects approximately 96.1% of the ODs and segments approximately 98.65% of exudates precisely. Thus, the technique provides a better segmentation and quantification precision. Also the complexity, cost and time of the system is reduced at the much comparable results. The proposed method also has the ability to eliminate blood vessels in the retinal fundus images, and it also discards the optic disc region to quantify exudates area precisely.

The method proposed for segmentation of exudates can also be utilized for analyzing and segmentation of other types of retinal lesions in retinal fundus images, which could be taken as a subsequent work. There exist some cases in which image illumination artifacts come in account in retinal fundus images where the proposed technique is not able to attain good segmentation performance. In other methods proposed the image illumination artifacts may influence the segmentation performance adversely, which could also be taken as additional problem of subsequent tasks to be solved.

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