A Survey on Automated Microaneurysm Detection in Diabetic Retinopathy Retinal Images
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Abstract—Automated retinal image analysis is becoming an imperative screening tool for early revealing of certain risks and diseases like Diabetic Retinopathy. Diabetic Retinopathy (DR) is the prominent cause of blindness in the world. Early detection of diabetic retinopathy can provide operative treatment. Early treatment can be conducted from detection of microaneurysms. Microaneurysms are the earliest clinical sign of diabetic retinopathy and they appear as small red spots on retinal fundus images. Microaneurysms are reddish in color with a diameter less than 125 μm. The existing trained eye care specialists are not able to screen the growing number of diabetic patients. So there is a need to develop a technique that is capable to detect microaneurysms as a part of diagnosis system, so that medical professionals are able to diagnose the stage of the disease with ease. Automated microaneurysm detection can decrease the workload of ophthalmologists and cost in DR screening system. Early automated microaneurysms detection can help in reducing the incidence of blindness. In this paper, we review and analysis the techniques, algorithms and methodologies used for the detection of microaneurysms from diabetic retinopathy retinal fundus images.

Keywords—Diabetic retinopathy; Fundus photographs; Automated detection; Microaneurysms.

I. INTRODUCTION

Due to modern living style, a list of people is getting affected with Diabetes. The World Health Organization evaluated that 135 million people have diabetes mellitus worldwide and that the number of people with diabetes will increase to 300 million by the year 2025 [1]. Diabetes is a systematic and chronic end organ disease that occurs when the pancreas does not secrete enough insulin or the body is unable to process it properly [2]. A side effect of diabetes is Diabetic Retinopathy in which different parts of the retina get affected. Diabetic retinopathy is a medical condition where the retina is damaged because fluid leaks from blood vessels into the retina. Doctors recognize diabetic retinopathy by examining the features, such as blood vessel area, exudates, hemorrhages, microaneurysms and texture. Diabetic retinopathy can be divided into three stages of non-proliferative retinopathy: mild, moderate, and severe and one stage of proliferative retinopathy [3].

Different retinal features such as blood vessels, optic disk, macula and fovea as shown in Fig. 1. Due to diabetic retinopathy different parts of the retina get damaged and lead to vision loss. Also the characteristics are changed due to different pathological conditions [2]. Due to changes in retinal features, new features such as microaneurysms, exudates, and hemorrhages appear in the retina as shown in Fig. 2. Diabetic Retinopathy is a frequent complication of diabetes and the most common cause of blindness in the working population of the western world.

Fleming et al. [4] have shown the role of microaneurysm and hemorrhage in automatic grading of diabetic retinopathy. One of the most important steps in the automated detection of DR is the detection of microaneurysms. Microaneurysms are amongst the earliest observable signs of the presence of diabetic retinopathy. Due to a large number of patients, the available ophthalmologists are not sufficient in handling all the patients, especially in rural areas [5]. Therefore, automated early detection of microaneurysms could ease the burden of ophthalmologists. Automated microaneurysms detection can also help the ophthalmologists in investigating and treating the disease more efficiently [6].

In this paper, we compare some of the methods for automatic detection of microaneurysms on the basis of two parameters: sensitivity and specificity. The objective of this paper is to review the relevant literature in the field of microaneurysm detection and to provide researchers with a
detailed resource of the available methodologies used for microaneurysms detection.

II. METHODOLOGIES USED IN MICROANEURYSM DETECTION

Automated microaneurysm detection is very useful in diagnosing the diabetic retinopathy for the prevention of blindness. With the help of automated system, the work of ophthalmologists can be reduced and the cost of detection of diabetic retinopathy can be reduced. Most of the existing methods of microaneurysms detection work in two stages: microaneurysms candidate extraction and classification. First stage requires image preprocessing for the reduction of noise and contrast enhancement. Image preprocessing is performed on the green color plane of RGB image because in green color plane microaneurysms have the higher contrast with the background. After that candidate regions for microaneurysms are detected. Then blood vessel segmentation algorithms are applied to extract blood vessel from the candidates for the reduction in false positives because many of the blood vessels may appear as false positives in the preprocessed image. Then feature analysis is used in which feature extraction and feature selection is performed to detect the microaneurysms. In second stage, the classification algorithm is applied to categorize these features into microaneurysm candidate (abnormal) and non-microaneurysm candidate (normal). The probability is estimated for each candidate using a classifier and a large set of specifically designed features to represent a microaneurysm.

In general the process for the detection of microaneurysms is concluded in Fig. 3.

![Diagram](image)

**Fig 3. The Process of Microaneurysm Detection**

Image preprocessing is performed in all the methods of microaneurysms detection. Image preprocessing is performed to minimize the intensity variation effect in the background across the image as described in [7-10]. Image preprocessing is performed on the green color plane of the RGB image because microaneurysms have higher contrast in the green color plane. To remove all gross shadings due to macula, shade-correction of fluorescein is performed so that global morphological and thresholding operators can be applied successfully. In the following subsections, we describe the various approaches to detect microaneurysm.

A. Morphological Processing

Morphological processing is the most common method used for detection of microaneurysm. Morphological processing is a collection of techniques that can be used for image component extraction.

In 1996, Spencer et al. [11] used morphological processing which detects microaneurysms present in fluorescein angiograms. After preprocessing stage, a bilinear top-hat transformation and matched filtering are used to provide an initial segmentation of the images. Then Thresholding is used to produce a binary image that contains candidate microaneurysms. Then a novel region-growing algorithm results in the final segmentation of microaneurysms.

Then Frame et al. [12] produced a list of features like shape features and pixel-intensity features on each candidate. Then the classifier use these features to classify each candidate as microaneurysm and non-microaneurysm.

Niemeijer et al. [6] used a hybrid approach to detect the red lesions by combining the prior works by Spencer et al. [11] and Frame et al. [12] with two important new contributions. Their first contribution is the use of new red lesion candidate detection system which is based on pixel classification. Blood vessels and red lesions are separated from the background by using this technique. Remaining objects are considered as possible red lesions after removal of vasculature. Their second contribution is the addition of a large number of new features to those proposed by Spencer-Frame. Then k-nearest neighbor classifier is used to classify the detected candidate objects. This method achieved 100% sensitivity and 87% specificity but the time required is more for initial detection of red lesions. Then Zhang and Fan [13] proposed a spot lesion detection algorithm that uses multiscale morphological processing. Using scale-based lesion validation, blood vessels are removed. This algorithm was tested on 30 retinal images and it achieved the sensitivity of 84.10% and predictive value of 89.20%.

Karnowski et al. [14] proposed a morphological reconstruction method for the segmentation of retinal lesions. In this method, the segmentation is performed by using ground-truth data at a variety of scales determined, to separate nuisance blobs from true lesions. The ground truth data is used to design post-processing classifiers to separate the machine segmented results into nuisance and actual lesion classes. This segmentation result is used to classify the images as “normal” or “abnormal”. This method was tested on 86 retinal images and it achieved a sensitivity of 90% and specificity of 90%. The weakness of this method is that classification features for the post-processing steps is inaccurate so this method can be improved on more realistic dataset.

Kande et al. [15] proposed an approach that takes into account the advantages of pixel-based classification and morphological based detection. Local entropy thresholding
algorithm is used to distinguish between enhanced red lesion segments and the background. Then morphological top-hat transformation is used to suppress the blood vessels and then SVM (Support Vector Machine) is used to classify the red lesions from other dark regions. This approach takes the same time as proposed in [11] and [12] and performs better. The sensitivity is 96.22% and specificity is 99.53% of this approach.

Then again automated microaneurysm detection method based on pixel classification and mathematical morphology was proposed by Kande et al. [16]. They have tested their method on more realistic dataset. In this method, matched filtering is used for the contrast enhancement of red lesions against the background. Then these enhanced red lesions are segmented by using relative entropy based thresholding to maintain the spatial structure of the red lesion segments. Morphological top-hat transformation is then used to suppress the enhanced blood vessels. Then support Vector Machine is employed for classifying the candidate red lesions from other dark segments. This method was tested on 89 retinal images selected randomly from three databases STARE [17], DIARETDB0, and DIARETDB1 [18] and it achieved a sensitivity of 100% and specificity of 91%.

Matei and Matei [19] used morphological operations, linear filtering and thresholding to identify the presence of specific retinal lesions of diabetic origin like microaneurysms and hemorrhages etc. Langroudi and Sadjadi [20] proposed a method for early diagnosis and screening of diabetic retinopathy. In this method, five types of lesions are detected based on morphology. These lesions include: Microaneurysm, Drusen, hard exudates, Soft exudates and Hemorrhage, each of these lesions is a sign of diabetic retinopathy. This method achieved a sensitivity of 92.5% and a specificity of 81.4% but this method can be improved by using some other efficient methods.

Then Ardimas et al. [21] used the mathematical morphology to detect the microaneurysms. In this method, the author has used mathematical morphology because microaneurysms tend to have typical shape. Adaptive histogram equalization, Canny edge detection, MAs optimum pixel size, and PAL size image processing is also considered in this method. The algorithm proposed in this paper consists of three stages: first of all preprocessing is done, then microaneurysms candidates are detected and at last, post processing is done to remove the unused features like optic disk and exudates. The performance of this paper is evaluated on the DIARETDB1 [18] database which consists of 89 retinal images.

B. Neural Network Approach

Kamel et al. [22] proposed a neural network approach for automatic detection of microaneurysms in retinal angiograms. The main purpose of using neural network is that it is able to detect the regions that contain the microaneurysms and reject other regions. So to achieve this goal, the image is divided into several regions or windows. To classify the input patterns into their desired classes, LVQ (Learning Vector Quantization) is used. From a grid of smaller image windows, the input vector of the neural network is derived. According to a novel multi-stage training procedure, the presence of microaneurysms is detected in these windows.

Usher et al. [23] also used neural network to detect the microaneurysms. First of all preprocessing is done. After preprocessing, microaneurysms are extracted using recursive region growing and adaptive intensity thresholding with “moat operator” and edge enhancement operator. For this method, the sensitivity of detecting the microaneurysms is 95.1% and specificity is 46.3%.

Garcia et al. [24] proposed an automatic method to separate the red lesions like microaneurysms or hemorrhages from retinal background. On the basis of properties of these lesions, a set of features are extracted from image regions and then subset is selected which best discriminate between these red lesions and the retinal background. Then, to obtain the final segmentation of red lesions, a multilayer perceptron is subsequently used. The algorithm was tested on 50 images with a set of 29 features that describe the shape and color of image regions. Using a lesion based criterion, a mean sensitivity is 86.1% and a mean positive predictive value is 71.4%. Using an image-based criterion, they achieved a 100% mean sensitivity and 60% mean specificity but there are some limitations also. This system missed red lesions close or connected to the vasculature. These lesions were considered as a part of the vasculature and were masked out along with the blood vessels from the final result.

Then again Garcia et al. [25] proposed a method in which this above limitation is improved. They proposed a method that extract a set of color and shape features from image regions by using morphological and region growing method and select by using logistic regression. For final segmentation of red lesions, four neural network (NN) based classifiers are used: MLP (Multilayer Perceptron), RBF (Radial Basis Function), SVM (Support Vector Machine) and a combination of these three neural networks using a majority voting schema. Using a lesion based criterion a mean sensitivity value is 86.01% and positive predictive value is 51.99%.

C. Classification

Niemeijer et al. [6] proposed a red lesion detection method based on a hybrid approach that combines the prior works by Spencer et al. [11] and Frame et al. [12]. The first method is based on pixel classification. By using this method, blood vessels and red lesions are separated from the background of an image and then the remaining objects are considered as red lesions. In second method a large number of features are added to those proposed by Spencer-Frame. Then by using K-nearest neighbor classifier and all features, the detected candidate objects are classified. To determine whether an image contains red lesions or not, this system achieved a sensitivity of 100% and a specificity of 87%.

Time required is more for the initial detection of red lesions in the previous approach so this limitation is improved by Balasubramanian et al. [26]. They proposed a candidate extraction method that is achieved by Automatic Seed Generation (ASG). Automatic Seed Generation (ASG) is devoid of Morphological Top Hat Transform (MTH). In this method, the author has combined two classifiers K-Nearest Neighbor (KNN) and Gaussian Mixture Models (GMM) and proposed this combination as Hybrid classifier to classify true red lesions from non-red lesions. This system achieved a sensitivity of 87% and 95.53% specificity but still there is a need to develop local contrast enhancement algorithms that
can distinguish very small features like red lesions from the background.

Then Jaafar et al. [27] proposed a computer-aided system to automatically identify red lesions from retinal fundus images. Firstly image pre-processing is done. Then red lesions are segmented from the background and other retinal structures by using a morphological technique. Then rule-based classifier is used to detect actual red lesions from artifacts. The main purpose of candidate classification is to classify each candidate as an actual red lesion or spurious red lesions. This system was tested on 219 images. At lesion level, this system achieved a sensitivity of 89.7% and a specificity of 98.6%.

Wenhua et al. [28] proposed a method to detect the microaneurysms using SVM (Support Vector Machine) in retinal fundus images. In this method, first of all a generalize histogram algorithms are used to enhance the images. Then blood vessels and any object which is too large to be a red lesion is removed. Then finally, extraction of microaneurysm is performed and its result is given as the input to the SVM to classify the microaneurysms. This system achieved an accuracy of 90%. For the detection of red lesions like microaneurysms, this approach is a desirable approach.

Hatanaka et al. [29] proposed an automated microaneurysm detection method that is based on feature analysis in retinal fundus images. Firstly image preprocessing is done then candidate regions for microaneurysms are detected using a double-ring filter. The texture features are also added in this method. 126 image features are determined and 28 components are selected by using PCA (Principal Component Analysis). Then candidates are classified using rule based classifier and an artificial neural network into microaneurysms and non-microaneurysms. In this method the author has used ROC (Retinopathy Online Challenge) dataset for identification of microaneurysm. This method achieved a true positive rate of 68% at 15 false positives per image.

D. Region growing

Spencer et al. [11] and Frame et al. [12] has used morphological top-hat transformation for vasculature detection. Then region growing algorithm was used to find a final candidate object set. Then Cree et al. [7] proposed a method for automatic detection of microaneurysms. In this paper the author has used region growing algorithm to find the underlying candidate morphology and then to distinguish microaneurysms from other spurious objects, features classification algorithm was used. This system achieved a sensitivity of 82% for detecting microaneurysms and specificity of 84%.

Streeter et al. [31] proposed a microaneurysms detection method using region growing algorithm in color fundus images. After the preprocessing, the blood vessels are removed. After that, thresholding and region growing algorithm is applied by taking a candidate seed image. After region growing, the features are extracted. This system achieved 56% of sensitivity at 5.7 false positives per image.

III. DATASET

For detection of microaneurysm, different authors have used different type of datasets like STARE, DIARETDB1 and ROC.

STARE [17] was initiated by Michael Goldbaum, M.D., at the University of California. This dataset is publicly available. STARE dataset consists of 81 retinal fundus images; these images were captured by a TopCon TRV-50 fundus camera and then digitized at 605 × 700. Out of these 81 images, 31 images are of normal retinas and 50 images are of diseased retinas. STARE dataset is used for evaluating the automatic OD (Optic Disk) localization method.

DIARETDB1 [18] was initiated by Tomi Kauppi for diabetic retinopathy detection from digital fundus images. This dataset is publicly available. It consists of 89 retinal fundus images of which 84 images contain some signs of diabetic retinopathy like microaneurysm and 5 images are considered as normal which do not contain any signs of diabetic retinopathy. These images were collected from a screening program and taken under a fixed imaging protocol. It contains the ground truth collected from several experts and a strict evaluation protocol.

ROC (Retinopathy Online Challenge) [19] was organized by Michael D. Abramoff, Bram van Ginneken and Meindert Niemeijer at university of Iowa. ROC aims to help the patients with diabetes by improving the CAD (Computer Aided Detection) of diabetic retinopathy. This dataset consists of 50 training images in which “gold standard” locations of microaneurysms are identified by the ophthalmologists. ROC also consists of testing images in which “gold standard” locations are not provided. The 50 training images include RGB color images in three different resolution: 768 × 576 pixels, 1059 × 1061 pixels, and 1389 × 1388 pixels; and in each different resolution, the number of images is 22, 3, and 25, respectively.

IV. EVALUATION AND PERFORMANCE MEASURE

In this section, the evaluation approaches and the performing measures are described.

From all the methods that are described in this paper can be classified into three approaches: pixel-based, lesion-based and image-based. In pixel-based approach, the detected microaneurysms are compared with the ground truth image pixel by pixel. In lesion-based approach, for comparison number of microaneurysms is used. Image-based classification is widely used. In image-based classification, the images are classified as normal images and abnormal images (diabetic retinopathy).

<table>
<thead>
<tr>
<th>Predicted Class</th>
<th>Actual Class</th>
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<tbody>
<tr>
<td></td>
<td>C1 (Yes)</td>
</tr>
<tr>
<td>C1 (Yes)</td>
<td>True Positives</td>
</tr>
<tr>
<td>C2 (No)</td>
<td>False Positives</td>
</tr>
</tbody>
</table>

Fig. 4. Confusion Matrix for Positive and Negative Tuples
For automated detection of microaneurysms, two measures are mostly used: sensitivity and specificity. Confusion matrix is used for measuring the sensitivity and specificity.

True positives- Correctly identified means microaneurysms found as microaneurysms.

True negatives- Correctly rejected means non-microaneurysms found as non-microaneurysms.

False positives- Incorrectly identified means non-microaneurysms found as microaneurysms.

False negatives- Incorrectly rejected means microaneurysms found as non-microaneurysms.

Sensitivity is the probability of a positive test given that the patient has disease.

\[
\text{Sensitivity} = \frac{\text{number of true positives}}{\text{number of true positives} + \text{number of false negatives}}
\]

Specificity is the probability of a negative test given that the patient has no disease.

\[
\text{Specificity} = \frac{\text{number of true negatives}}{\text{number of true negatives} + \text{number of false positives}}
\]

Sensitivity is essentially how good a test is at finding something if it is there, means the proportion of actual positives which are correctly identified. Specificity is a measure against false positives, how accurate a test is, means the proportion of negatives which are correctly identified. We have classified the papers based on evaluation approach. In this paper, we will compare only the papers that show the number sensitivity and specificity as shown in Fig. 5.

From Fig. 5, we can see that lesion-based approaches and image-based approaches give high value of sensitivity but low value of specificity. Many of the researchers have used this approach for the evaluation of their methodologies to detect the microaneurysm for screening the patients.

V. CONCLUSION

Automatic detection of microaneurysm presents many of the challenges. The size and color of microaneurysm is very similar to the blood vessels. Its size is variable and often very small so it can be easily confused with noise present in the image. In human retina, there is a pigment variation, texture, size and location of human features from person to person. The more false positives occur when the blood vessels are overlapping or adjacent with microaneurysms. So there is a need of an effective automated microaneurysm detection method so that diabetic retinopathy can be treated at an early stage and the blindness due to diabetic retinopathy can be prevented.

In this paper, some existing methods are reviewed to give a complete view of the field. On the basis of this work, the researchers can get an idea about automated microaneurysm detection and can develop more effective and better method for microaneurysm detection to diagnose diabetic retinopathy.

REFERENCES


![Fig. 5 Performance measures: sensitivity and specificity based on 3 approaches: image, lesion, and pixel](image-url)