Detection of Abnormal Features in Digital Fundus Image Using Morphological Approach for Classification of Diabetic Retinopathy

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ABSTRACT: Over the past few years diabetic retinopathy has proved to be a leading cause of blindness in adult population. WHO studies in 2002 showed that the diabetic retinopathy accounts for nearly 5% of the 37 million visually challenged people worldwide. The number of diabetic retinopathy patients around the globe is expected to increase from 127 million in 2010 to 191 million in 2030. An innovative and effective mass screening system needs to be developed for meeting the ever increasing number of patients with the limited number of ophthalmologists. The digital fundus image of retina is being effectively used for the diagnosis of diabetic retinopathy. Microaneurysms, haemorrhages and exudates are the abnormal features commonly observed in the retinal image of a person affected by diabetic retinopathy. In this paper a method using mathematical morphological operations and edge detection to detect these lesions is discussed. The detected features are used to classify the different stages of diabetic retinopathy. The method discussed is fast and robust (applicable on low quality images) and hence suitable for mass screening of patients.

KEYWORDS: Retinal fundus image, Optic Disc, Microaneurysms, Haemorrhages, Exudates, mathematical morphology, Top-hat Transform.

I. INTRODUCTION

Diabetes mellitus [1], commonly referred to as diabetes describes a group of metabolic diseases in which the person has high blood glucose (blood sugar), either because insulin production is inadequate (Type 1 Diabetes), or because the body's cells do not respond properly to insulin (Type 2 Diabetes), or both. Diabetes leads to a variety of pathologies in the body namely Diabetic Neuropathy [2], Diabetic Nephropathy [3], and Diabetic Retinopathy [4-9]. Diabetic retinopathy results due to the damage to the tiny blood vessels that supply nutrients to the retina [6]. They leak blood and other fluids such as lipid proteins, fats etc. that cause swelling of retinal tissue and affects normal vision. It usually affects both eyes. The longer the patient has Diabetes there is more likelihood that the person will develop the Diabetic Retinopathy. If Diabetic Retinopathy is not treated for long time it can cause permanent blindness [5].Presently diabetic retinopathy can be accounted for approximately 5% of global blindness [4].

Based on the damage done to the retina the disease is classified into two stages. Non-proliferative diabetic retinopathy (NPDR) is the early state of the disease in which there are no or minimal symptoms of disease. In NPDR, the blood vessels in the retina are weakened causing tiny bulges called micro-aneurysms [5] to protrude from their walls. These tiny bulges may leak blood or other fluids such as fats or proteins.Proliferative diabetic retinopathy (PDR) [5] is the more advanced form of the disease. At this stage, the retina becomes severely oxygen deprived and so new blood vessels starts forming to supply oxygen to the retina. These new vessels are abnormal so they are very fragile and tends to burst, leaking blood into the vitreous (fluid that fills the space in front of retina) clouding vision through a process called vitreous haemorrhage [5].

Often there are no visual symptoms in the early stages of diabetic retinopathy. Early detection and treatment can limit the potential for significant vision loss from diabetic retinopathy. Both people with Type 1 as well as Type 2 diabetes are at risk for the development of diabetic retinopathy. The longer a person has diabetes, the more likely they are to develop diabetic retinopathy, particularly if the diabetes is poorly controlled. In the early stages of Non-proliferative Diabetic Retinopathy, treatment other than regular monitoring may not be required. Following the doctor's advice for diet and exercise and keeping blood sugar levels well-controlled can help control the progression of the disease. That is why the early detection of Diabetic Retinopathy and regular eye checking is extremely important for all the diabetes patients [9].
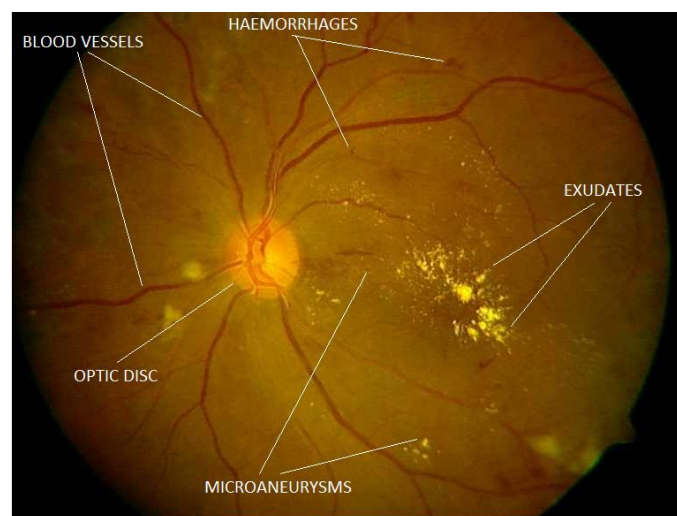

Figure 1.Illustration of various features on a typical retinal fundus image.

Micro aneurysms, Haemorrhages and Exudates are the Characteristic features seen at different stages of Non Proliferative Diabetic Retinopathy [5]. Microaneurysms are the first sign of Diabetic Retinopathy which can be observed on the retinal fundus image. As the disease progresses some of the capillaries rupture and appear as small dots or larger blots or flame-shaped haemorrhages [8] which appear red on fundus image. If these capillaries leak precipitates of lipids, serum proteins then it will lead to yellow lesions called as exudates [5]. Based on the extent of the presence of these features the diabetic retinopathy is classified into Mild Non-proliferative Diabetic Retinopathy, Moderate Non-proliferative Diabetic Retinopathy, and Severe Non-proliferative Diabetic Retinopathy.

Various methods have been used for segmentation of the diabetic features. Segmentation of exudates using mathematical morphology [11] has been proved particularly useful [12-19]. Morphological Top-Hat transform [17], edge detection [18, 19] and recursive region growing [14, 15] are some widely used methods for segmentation of microaneurysms and haemorrhages.

II. RELATED WORK

Ramanuka et al [12] used morphological operations to detect hard exudates. Fuzzy logic was further used to classify the hard exudates. Zhang et al [13] used separate methods for small and large exudates. Large exudate candidates were obtained by applying mean filter on the preprocessed image followed by a reconstruction. Morphological top-hat transform was used to detect the small exudates.

Sopharak et al [14] used local variance operator and morphological operations such as opening, closing and reconstruction to extract exudates. Otsu algorithm was used to determine the thresholds. Sinthanayothin [15, 16], used the recursive region growing approach to separate exudates which essentially has the sharp edges. Further for extracting the microaneurysms and Haemorrhages a Moat operator was used to create sharp edges in the image on

which recursive region growing technique was used. Spencer et al [17] used bilinear top-hat transformation to detect microaneurysms from a shade corrected image.

III. PROPOSED ALGORITHM

The green channel of the image is selected for the segmentation of the features both normal and abnormal because in has the maximum contrast than the original or red or blue channel. Then the contrast of the green channel is increased by using either contrast limited adaptive histogram equalization [CLAHE] or histogram equalization [11] depending upon suitability.

A.   Optic Disc Detection

The optic disc corresponds to the brightest component of the retinal image. The intensity levels of optic disc are very similar to that of exudates so it is very important to detect the optic disc separately. Let I_1 be the grayscale image of the green channel of the original image. Image I_1 is pre-processed using histogram equalization to get image I_2. Candidate optic disc region is then separated from I_2 by segmenting the region of maximum intensity. Image I_3 is then obtained by applying a 3x3 median filter to remove the stray pixels (Salt and Pepper noise). Then a morphological opening operation (o) using a flat disc shaped structuring element (D_1) is performed on I_3.

$$I_4 = I_3 \; o \; D_1$$

A Suitable Structuring element is chosen that differentiates between the optic disc and exudates based on size. It is assumed here that any stray exudates detected are smaller than the size of optic disc. The opening operation will eliminate the smaller exudates present if any.

B.   Blood Vessel Detection:

Blood vessel segmentation is a significant step in the red lesion detection. Since the blood vessels and red lesions namely microaneurysms and haemorrhages are both red in colour the blood vessels need to be extracted out of the fundus image in order to effectively detect the microaneurysms and haemorrhages. A Contrast limited adaptive histogram equalization (CLAHE) is performed on the negative of I_2 to get resultant image I_5. Image I_6 is obtained by performing Top-hat filter operation on image I_5 using a flat disc shaped structuring element (D_2). Top-hat filtering is the equivalent of subtracting the result of performing a morphological opening operation on the input image from the input image itself.

$$I_6 = I_5 - (I_5 \; o \; D_2)$$

Suitable threshold is used to segment out the blood vessels from image I_6. This threshold is selected based on the a-priori knowledge of the quality of the image. The resultant image (I_7) comprises of blood vessels along with haemorrhages, micro-aneurisms and other stray structures. After removing structures that have area less than a decided threshold we get image I_8 containing only blood vessels.

C.   Exudate detection:

Exudate detection is a complicated task due to the presence of many bright structures which can be mistaken into exudates. They are optic disc, Optic nerve fibres, reflections in the middle of the vessels and reflections which are present particularly on retina of young patients [13]. However, most of these structures especially optic nerve fibres do not have edges as sharp as exudates. False detection of non-exudate feature is avoided by using a unique technique involving edge detection, morphological closing and logical AND operation. Sharp edges were extracted from image I_1 using Sobel filter to obtain image I_8 .A morphological closing operation ($\cdot$) is performed on I_8 to fill the edges using a flat disc shaped structuring element (D_3).

$$I_9 = I_8 \cdot D_3$$

The CLAHE is applied on the image I_1 subsequently bright region is extracted using a suitable threshold to get image I_{10}. Logical AND operation is then performed between image I_{10} and image I_9.

$$I_{11} = I_{10}. \; AND \; I_9$$

The Optic disc then subtracted from the resultant image to give the exudates.

$$I_{12} = I_{11} - I_4$$

D.   Microaneurisms and Haemorrhage Detection:

The microaneurysms and dot haemorrhages are Structures with sharp edges and circular in shape [18]. I_{13} is obtained by applying Prewitt edge detector on I_1. The detected edges are then filled by applying morphological closing operation by using a flat disc shaped structuring element (D_4).

$$I_{14} = I_{13} \cdot D_4$$

The image obtained contains microaneurysms and Haemorrhages and blood vessels.Logical AND operation is then performed between image D_{14} and imageI_7.

$$I_{15} = I_{14} \ AND \ I_7$$

This step removes the false detection of the red lesions. Finally the blood vessels (I_8) are subtracted from I_{15} to get the red lesions.

$$I_{16} = I_{15} - I_8$$

Microaneurysms and haemorrhages are further separated from each other depending on the difference in their sizes. Structures having area smaller than a threshold are classified as candidate microaneurysms (I_{17}). The candidate microaneurysms contain small fragments of blood vessels along with microaneurysms. Since these fragments are thin linear structures these are eliminated by applying a morphological opening operation with a disc shaped structuring element (D_5).Structures bigger than microaneurysms are classified as candidate haemorrhages. These also contains fragments of blood vessels which are eliminated by applying a morphological opening operation with a disc shaped structuring element (D_6) having radius greater than that of D_5.

IV. **RESULTS**

Two different images are considered. One image is used for detection of the optic disc and exudatesanother one is used for the detection of blood vessels, microaneurysms and haemorrhages.

a.   Optic Disc Detection

Input fundus image shown is shown in figure 2a.Gray scale image of the green channel of input image is shown in figure 2b.After applying histogram equalization on the image figure 2b we get contrast enhanced image figure 2c. Segmenting out the region of maximum intensity level gives all the bright regions in the image which contains optic disc and some false detection which typically from small exudates. These features are removed by performing several morphological opening operations. The obtained image is then morphologically dilated by using a flat disc shaped structuring element of small radius. Figure 2d shows the detected optic disc.
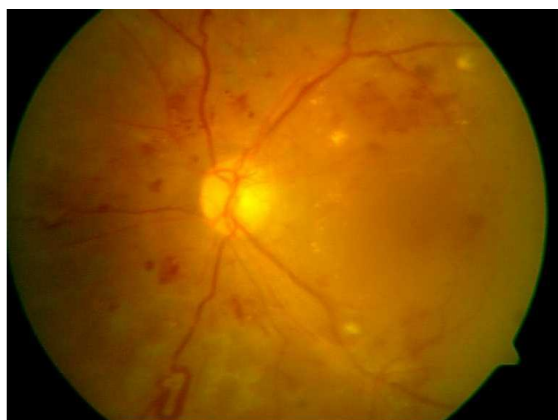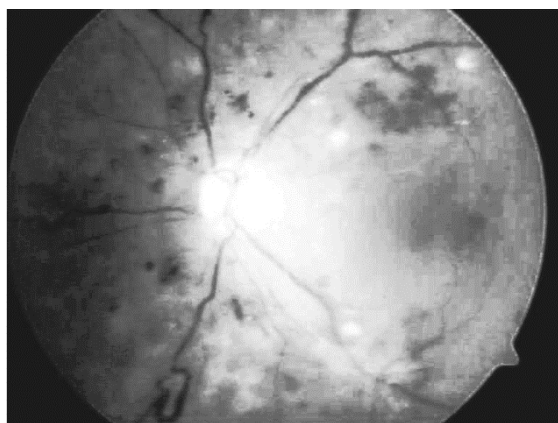

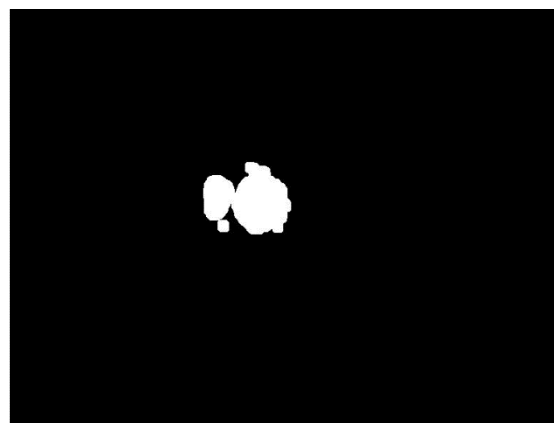2a   2b
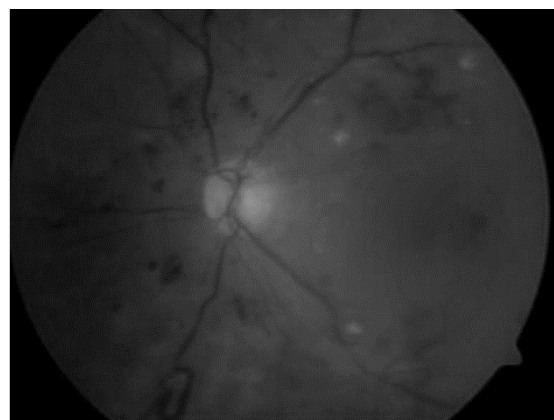
| 2c | 2d |

Figure 2.Illustration of the Optic Disc extraction:2a) Input fundus image ,2b) The grayscale image of green channel , 2c) image after applying histogram equalization, 2d) detected optic disc.

b.   Blood Vessel Detection

The   image shown in figure 3a isconsidered as the input image for blood vessel detection.The inverted histogram equalized image of grayscale image of green channel of input image as shown in figure 3b is filtered using top-hat transform. The top-hat transformed image (figure 3c) is then made binary using a suitable threshold. After binarization blood vessels as well as noise pixels, microaneurysms and haemorrhages are also present in the image. Suitable area threshold is used to remove these small structures. After removal of small objects we get the blood vessels as shown in figure 3d.

| 3a | 3b |
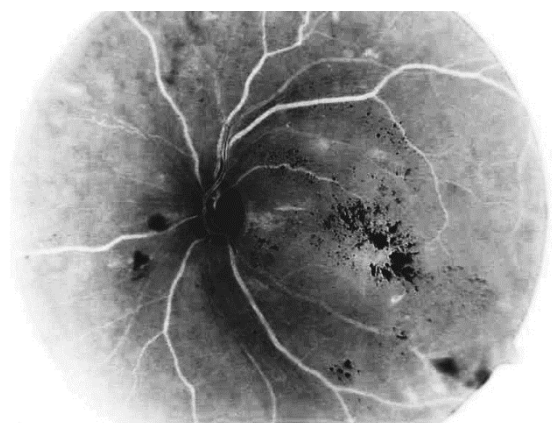
3c



3d

Figure 3.Illustration of blood vessel extraction: 3a) Input fundus image, 3b) negative of histogram equalized image, 3c) Top-hat filtered image, 3d) extracted blood vessels.

c.   Exudates Detection

Image shown in figure 2a is considered as the input image and a Sobel edge detector is used to find the edges. Figure 4a shows the closed edges, these typically involve blood vessels, microaneurysms, haemorrhages and exudates. Logical AND operation is performed between the image with bright region shown in figure 4b and figure 4a. This gives output as in figure 4c which contains some bright pixels in the optic disc region. From this image the earlier segmented Optic disc is subtracted to get the exudates as shown in figure 4d.
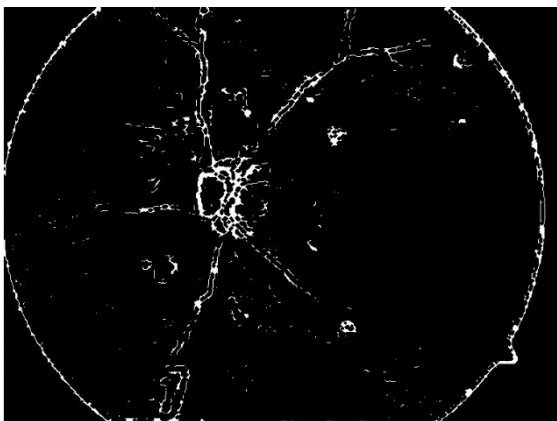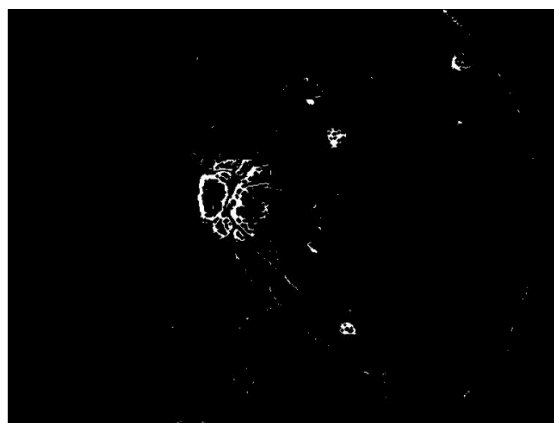

4a
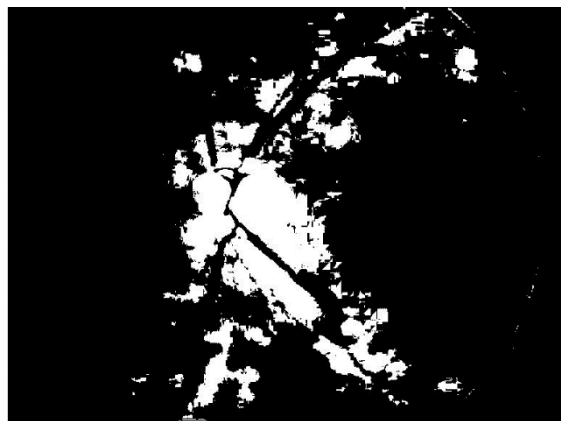
4b

| 4c | 4d |

Figure 4.Illustration of exudate extraction:4a) all structures in retinal image with sharp edges, 4b)all bright regions in the image, 4c) structures with sharp edges as well as high intensity, 4d) exudates.

d.   Microaneurysm and haemorrhage Detection

Image shown in figure 3ais considered as the input image. The edges detected by Prewitt filter after filling with closing operation contains blood vessels, exudates, microaneurysms and haemorrhages and is shown in figure 5a. Logical AND operation is then performed between this image and image 3dto get Figure 5b. Blood vessels are then subtracted from resultant image to give microaneurysms and haemorrhages with presence of noise pixels and small fragments of blood vessels. Small noise pixels are eliminated by performing a morphological opening operation by a disc shaped structuring element and small radius. Small structures within normal range of MAs are considered as MAs and separated from rest and shown in figure 5c. Larger fragments of blood vessels are linear structures, so when morphological opening operation with little larger radius is performed these fragments are removed leaving only true dot haemorrhages as shown in figure 5d.
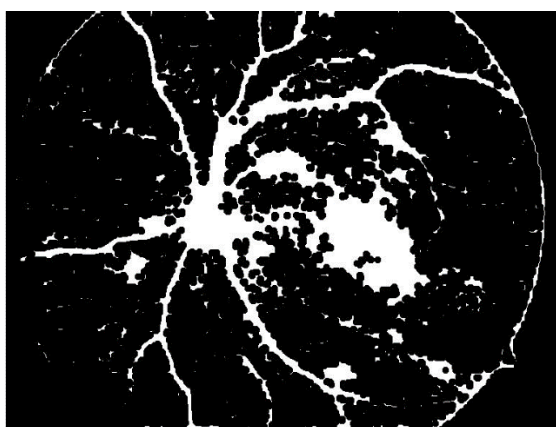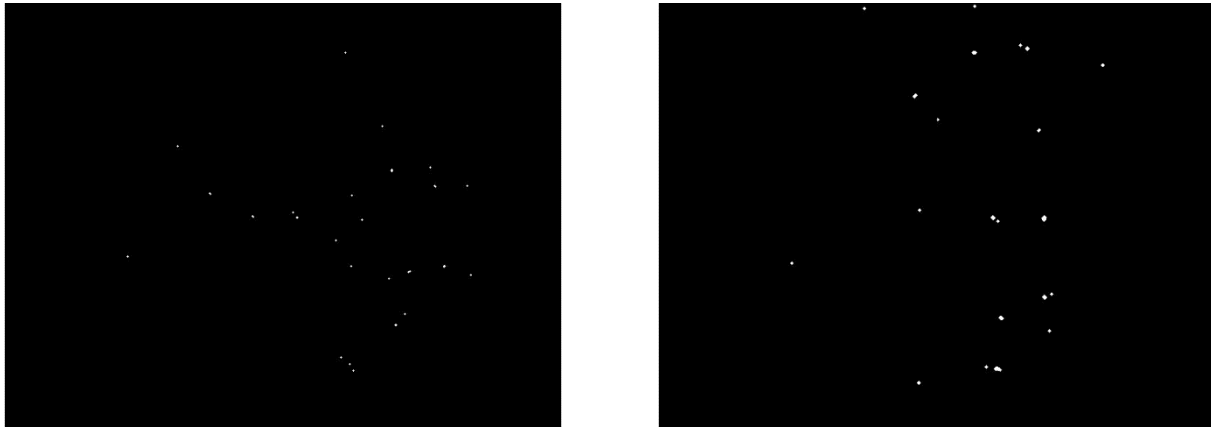

| 5a | 5b |
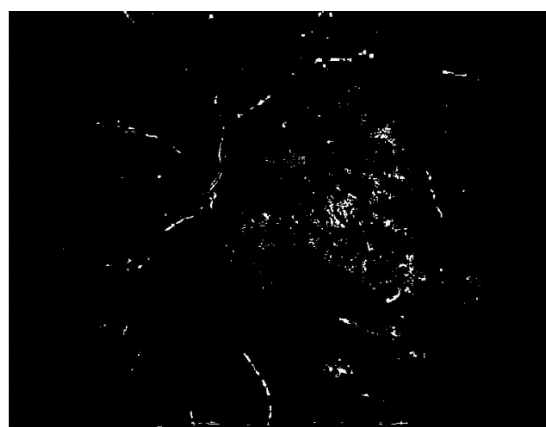
5c

5d

Figure 5.Illustration of microaneurysm and haemorrhage extraction: 5a) structures with sharp edges, 5b) microaneurysms and haemorrhages with small fragments of blood vessels and noise, 5c) microaneurysms, 5d) dot haemorrhages.

V. CONCLUSION AND FUTURE WORK

The fast and efficient early detection of Diabetic Retinopathy is only possible if there is an effective method for segmenting the diabetic features in the fundus image. The above proposed methods presents a fast, effective and robust way of detecting diabetic features in the fundus images which can be used for classification of the images based on the severity of the disease. Using the extracted features a classifier can be designed which will classify the images into several categories. Since manually detecting the presence of diabetic features especially tiny microaneurysms and haemorrhages is very difficult the proposed method can be of great help to the ophthalmologists' for mass screening of patients.

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