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Abstract

A short abstract: Retinal disorders are among the most dangerous diseases because many of them may lead to blindness if not early diagnosed and managed. Medical screening is very important as it allows the early diagnosis of the disease. Only ophthalmologists who have enough experience can differentiate between normal and abnormal retinas at the early stages of the disease. So, screening routines of the retina are very expensive and rarely to be done. In this work we provide a computer-aided screening system for the retinal disorders. The system could be used easily by the young physicians as it can automatically detect the early symptoms of abnormalities such as microaneurysms, hemorrhage and exudates. Using newly proposed image processing algorithms, we implemented a screening method based on the experience of the ophthalmology experts.

Keywords: computer-aided diagnosis, hemorrhage, microaneurysm detection, contrast enhancement, morphological segmentation.

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Abstract

Retinal disorders are among the most dangerous diseases because many of them may lead to blindness if not early diagnosed and managed. Medical screening is very important as it allows the early diagnosis of the disease. Only ophthalmologists who have enough experience can differentiate between normal and abnormal retinas at the early stages of the disease. So, screening routines of the retina are very expensive and rarely to be done. In this work we provide a computer-aided screening system for the retinal disorders. The system could be used easily by the young physicians as it can automatically detect the early symptoms of abnormalities such as microaneurysms, hemorrhage and exudates. Using newly proposed image processing algorithms, we implemented a screening method based on the experience of the ophthalmology experts.

Keywords: computer-aided diagnosis, hemorrhage, microaneurysm detection.

1.0 Introduction

Blindness is an intimidating problem. Many life difficulties and risks could be caused by blindness. According to the World Health Organization (WHO), blindness is defined as a corrected visual acuity below 3/60 on the Snellen scale for the best eye, or a central visual field diameter of less than 10°. It is estimated that about 180 million people worldwide have a visual impairment. Of these, 45 million persons are blind and 135 million are partially sighted. These figures are expected to double over the next 25 years due to combination of an increasing population and aging worldwide. The most common causes of blindness are cataract, glaucoma, and retinal disorders such as age-related macular degeneration (AMD) and diabetic retinopathy (DR) [1]. While cataract and glaucoma can be treated surgically, there is no curative treatment for the macular degeneration and the retinal vascular diseases till now. So, AMD and retinal vascular diseases, specially diabetic retinopathy, are the major causes of untreatable blindness worldwide. To prevent blindness caused by retinal disorders, they should be early diagnosed and then the spread of the disease can be stopped. So, screening of the retina is of most importance in this aspect. Unfortunately, screening of the retina is costly and should be achieved by highly qualified ophthalmologists. This motivated us to design and implement a computer-aided screening system that can automatically detect the abnormal symptoms on the retina in their early stages. This system could be used by young physician because it depends only on capturing digital images of the retina. These images can be processed by the system to decide whether the patient has the markers of retinal disorders, that might lead to blindness if left untreated, or not. The system is assumed to be able to determine the severity of the disease and the urgency for management.

Since AMD and (DR) are the major causes of blindness, we provide robust methods for the early detection of such diseases. In their early stages, these diseases are characterized by the presence of microaneurysms, hemorrhage and exudates in the retina. While exudates appear as yellow irregular regions in the fundus photgraph, microaneurysms and hemorrhage appear as red spots with irregular boundaries for the later as shown in figure 1. According to how much these symptoms appear on the retina, the severity of the disease could be estimated. In a previous work, we published a new method for the detection of blood vessels and exudates in retinal images using morphological image processing techniques [2]. In this work we propose some method for the detection of hemorrhage and microaneurysms together with the presentation of the screening system.

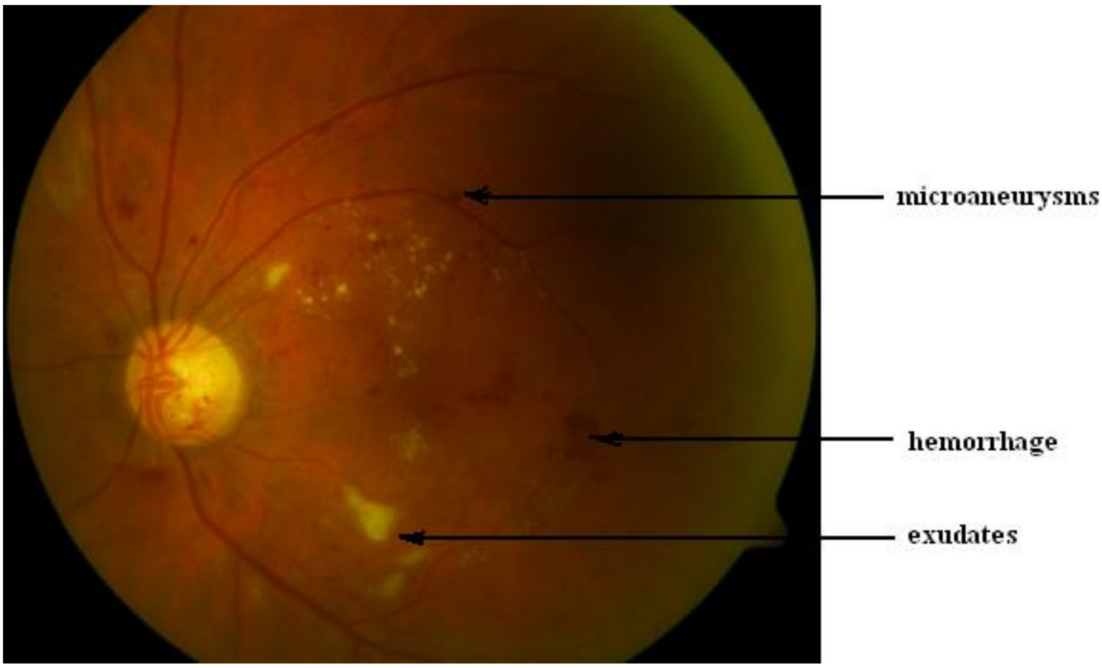


Figure 1. image of a retina with microaneurysms, hemorrhage and exudates pointed to.

Several techniques have been developed for the detection of hemorrhages and microaneurysms in fundus images. Joshi et al. in [3] used image subtraction to extract the blood vessels and hemorrhages. They also used mathematical morphology to suppress blood vessels and to highlight only hemorrhages. The authors in [4] used feature extraction based on pixel classification to detect red candidates and distinguish between microaneurysms and hemorrhages using k-nearest neighbor classifier. Region growing segmentation technique, intensity threshold and edge enhancement are used to extract red lesions are presented in [5]. Then they differentiate between hemorrhage and microaneurysms using neural network classification. Shade correction and image normalization of the green channel then diameter closing is used to detect candidates which are classified into real microaneurysms and other objects in [6]. Meindert et al. [7] compared the results of five different methods, produced by five different teams of researchers on the same set of data for microaneurysms detection. In one method, normalization of the green component of the retinal images using median filtering. Then, vessels are detected and removed using a top-hat transform and morphological reconstruction. The candidates are obtained and each candidate is segmented using region growing technique. A new approach based on multi-scale correlation filtering (MSCF) and dynamic threshold was developed in [8] to detect microaneurysms. Automated microaneurysm detection method based on double-ring Filter was achieved by the authors in [9]. In [10], a method to detect the hemorrhages using hue saturation value (HSV) space was proposed. Automated fundus photograph analysis algorithms for the detection of primary lesions and a computer-assisted diagnostic system for grading diabetic retinopathy (DR) and the risk of macular edema (ME) are introduced [11].

In this work, we propose a fast and an accurate method for the detection of microaneurysms and hemorrhages in fundus photographs. The detection of such disorders could be greatly improved by the new pre-processing algorithm which we propose in this paper. The power of the proposed pre-processing technique comes from the fact that it selectively enhances the contrast of microaneurisms and hemorrhage. Because the presence of microaneurysms and hemorrhage is the early signs of diabetic retinopathy, their detection would be an important issue for screening purposes.

The paper is divided into four main sections. In the first section, we introduce to this work with a brief presentation of the work done previously in this area of research. The materials and methods used in this work, are explained in details in the second section. The results are presented and discussed in the last section. Finally, we conclude our work and point to our future work.

2.0 Materials and methods

A dataset of about one hundred retinal images were collected for this work. They include most of the retinal disorders as well as some images of normal retinas. Some of the image in this dataset were collected using a VISUCAM Carl Zeiss fundus camera located at the biophotonics lab – NILES – Cairo University. The others were collected form the free access database STARE.

Fundus images usually taken as colored or graylevel images. Often, The green component of the colored image has the highest contrast and more information because it's like red-free illumination images. Normally, the blood stream in the graylevel images appear as dark objects in brighter background. While in the dye-injected patients, they appear as bright objects in darker background which results in higher contrast because of the fluorescence effect. Trials are always done to minimize the use of the dye because of cost and patient comfort requirements. So, researchers try to increase the contrast of images taken without the injection of a dye. Also, it is difficult to the physician to capture a high quality fundus images because of many reasons such as non uniform illumination, the limited control of the patient movement and the focusing required from the patient and for the system itself. So, image pre-processing is always required to enhance the images.

2.1 Proposed method

In an attempt to overcome the above-mentioned drawback related to enhancement of retinal images, we tried many of the pre-processing techniques. As we are interested in detecting dark objects such as microaneurisms and hemorrhage, we proposed a new pre-processing technique that can selectively increase the contrast of such objects. Segmentation of the anatomical structures and lesions can then be achieved using suitable algorithms. The steps of the proposed method are described below.

2.1.1 Pre-processing

The images collected for this work were investigated to select the images with hemorrhage, microaneurysms and exudates. The images were then pre-processed to selectively increase the contrast of micoaneurysms and hemorrhage because of the interest in detection of these lesions. We proposed a new preprocessing technique based on frequency domain filtering. As it is well known, if a high pass filter is applied to an image, it will sharpen this image. That is to say that the contrast of objects in relation to their backgrounds will be increased. So, high-pass filtering of an image increases the intensities of the objects while decreasing the intensities of their backgrounds as shown in figure 2 c. So, subtracting a high pass-filtered image from the original image would smooth the bright objects in relation to their backgrounds while decreasing the intensities of dark objects in relation to their backgrounds. Since we are interested in detecting microaneurysms and hemorrhage which appear as dark objects in the graylevel images, we can use this filtering and subtraction technique to selectively increase the contrast of dark objects such as microaneurisms and hemorrhage wile minimizing the contrast of bright objects such as exudates and optic disk. The pre-processing method can be described using the following equation:

$$g(x,y) = f(x,y) - af_{hpf}(x,y) \quad (1)$$

Where: $f(x,y)$ is the original graylevel image, $f_{hpf}(x,y)$ is the high pass-filtered image multiplied by a factor a and $g(x,y)$ is the resultant image. Figure 2 shows the original colored image and its green component in the upper row and the result of high pass filtering and the final result in the lower row. From this figure, we can observe that the contrast of the bright objects (exudates) is increased. This filtered image is then multiplied by 2 and subtracted from the original graylevel image. This leads to decreasing the contrast of exudates and enhancing the appearance of microaneurysms and hemorrhage in the final image.

2.1.2 Segmentation of retinal image

A good screening system should be able to detect any type of abnormality associated with diabetic retinopathy with high sensitivity. The most important signs are microaneurysms, hemorrhages (red lesions) and exudates (bright lesions). Also it is important to extract the normal structures such as the blood vessels tree, the optic disc and the macula. In a previous work, we provided robust algorithms to detect the optic disc, the blood vessels, the macula and the exudates [2]. To get a good screening system, we provide some methods to detect the other two abnormalities: microaneurysms and heamorrhages.

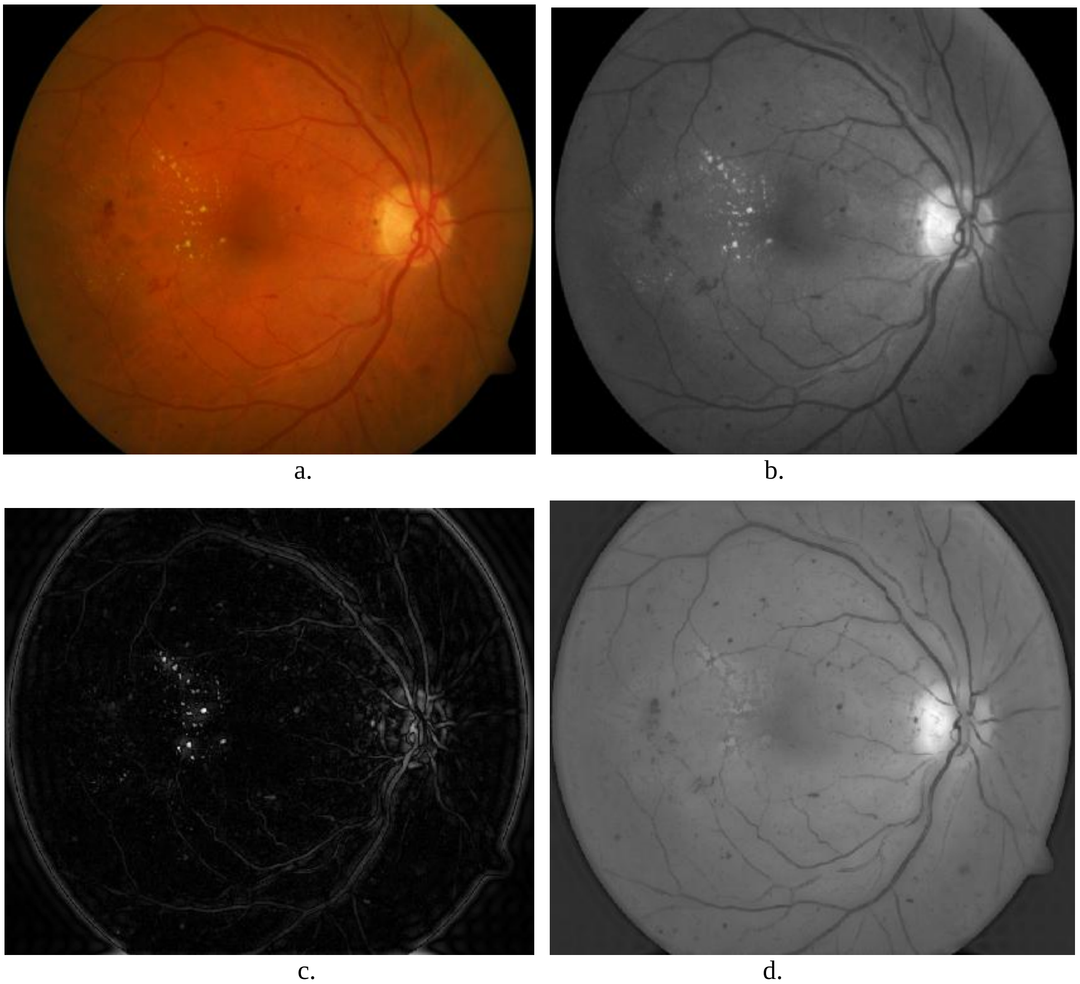


Figure 2. a. Original colored image, b. green component, c. high pass-filtered image and d. pre-processed image.

Microaneurysms appear as red spots of circular shape with similar color as blood vessels in color fundus images. Their diameter is smaller than 125 μm. They may appear as disconnected from the blood vessels tree because they are situated on capillaries, and capillaries are not visible in color fundus images [6],[12]. Also heamorrhages have the same color as the blood vessels but with irregular shapes. The difference in shape and size between microaneurysms and heamorrhages help us to distinguish between them.

After applying the pre-processing step described above, microaneurysms and heamorrhages will be of higher contrast. As microaneurysms and heamorrhages are dark regions in a bright background, we can detect them by using morphological filing operation on graylevel images. If the original is subtracted from the filled one, then we have an image that contain all the dark regions (blood vessels tree, macula region, microaneurysms and heamorrhages). We can obtain a binary image by simple thresholding as demonstrated in figure 3.

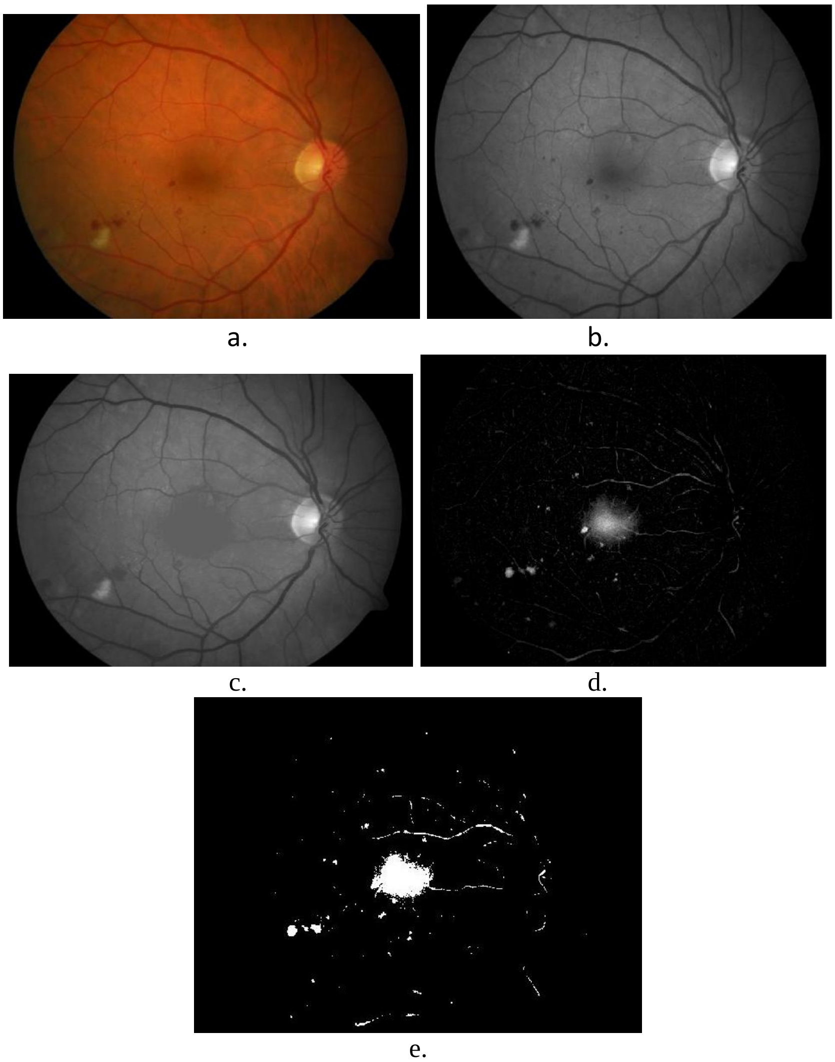


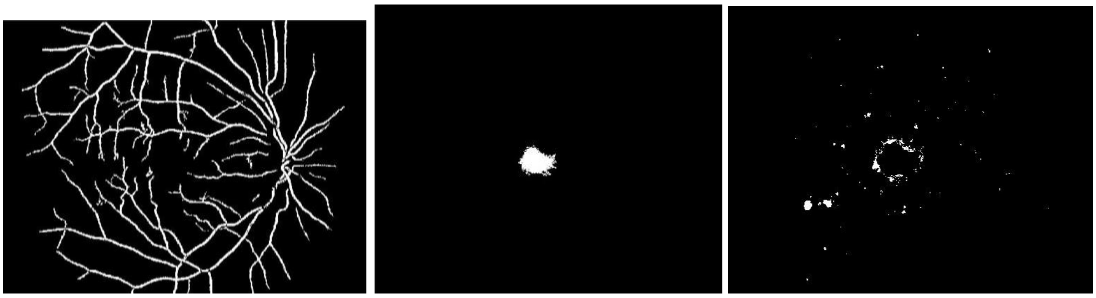
Figure 3. Dark regions detection: a. original image, b. green component, c. green component after filling operation, d. subtraction of c and b and e. dark regions after threshold.

2.1.3 Blood vessels tree detection

Now, we need to extract the blood vessels from the result image to obtain an initial estimation of candidate regions (microaneurysms and heamorrhages). This could be done by closing the binary image using two line structuring elements of different sizes rotated by different angles as in described in [2]. The detected blood vessels is shown in figure 4 a.

2.1.4 Macula detection

The macula is the area of acute vision within the retina. It appears as dark and homogeneous area near the optic disc, approximately 2.5 times the diameter of the optic disc from the centre of optic disc [13]. It can be extracted by region growing algorithm. To segment the macula, we manually select a point in the fovea (the center of the macula), then by a region-growing algorithm, the macula was extracted as the connected region around the fovea as described in [14]. Figure 4 b shows the result of macula detection.



a. b. c.

Figure 4. Initial estimation of microaneurysms and heamorrhages: a. blood vessels detection, b. macula detection and c. initial estimates of lesions.

2.1.5 Detection of microaneurysms and heamorrhages

After the removal of blood vessels and macula from the image obtained by morphological filling and segmentation, the result is an initial estimation of microaneurysms and heamorrhages as shown in figure 4 c. The final detection of these lesions can be obtained by applying the morphological reconstruction algorithm described in [15, 16] and given by:

$$h_{k+1} = (h_k \oplus b) \cap I_{in} \tag{2}$$

Where, h_k is the marker image at the k^{th} iteration (h_1 is the image contains the inverted initial estimate of microaneurysms and heamorrhages superimposed on the inverted original image), b is the structuring element and I_{in} is the input image (the inverted green component). This is an iterative process which must be repeated until no changes occur in h. The final iteration result is then subtracted from the inverted green component and thresholded to get the final estimate of microaneurysms and heamorrhages. Figure 5 shows the different steps of this method.

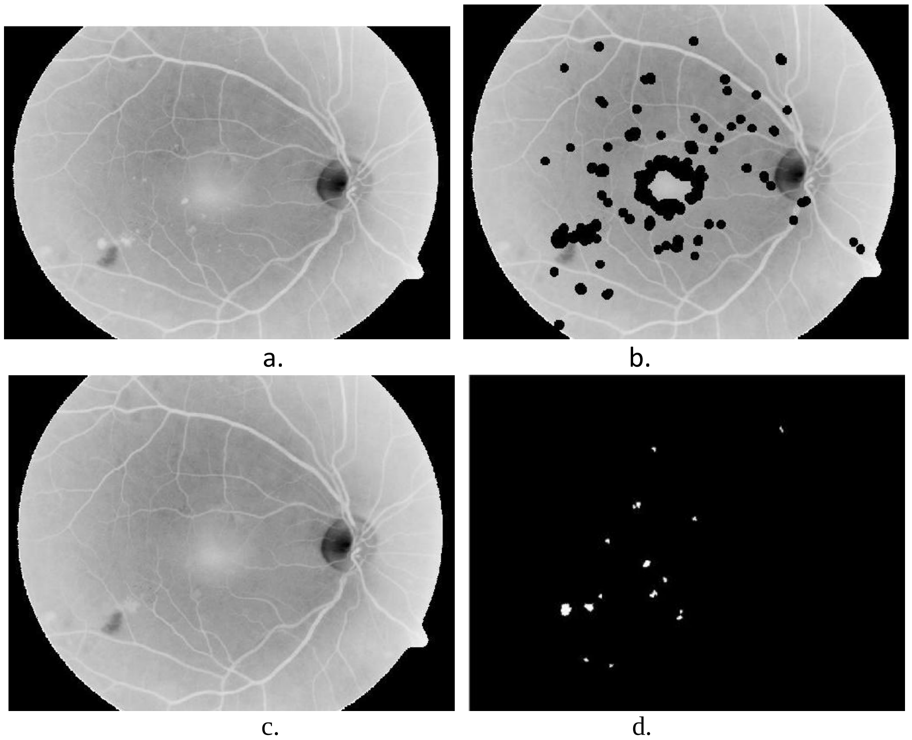


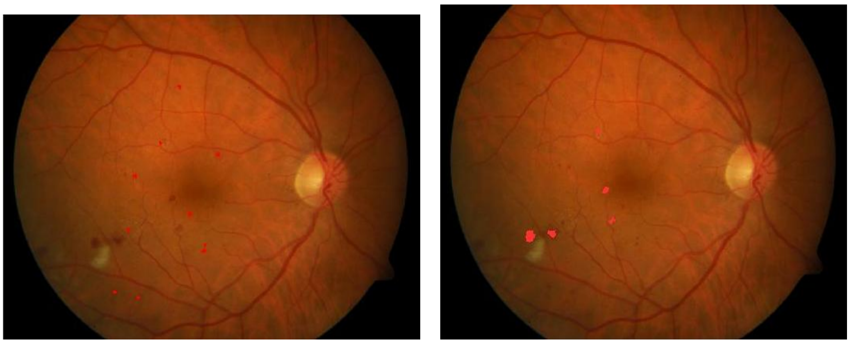
Figure 5. **Image reconstruction: a. mask image Iin , b. marker image, c. the result of reconstruction process and d. final estimation of microaneurysms and heamorrhages after thresholding.**

2.1.6 Differentiation between microaneurysms and heamorrhages

The obtained binary image contains a final estimation of microaneurysms and heamorrhages together. Now we need to separate the microaneurysms from heamorrhages and remove any false features come from noise. Microaneurysms are close to circular structures with small diameters but heamorrhages are irregular shapes. To separate them, all the connected components in the binary image are detected. For each connected components, the area, the minor axis length and the major axis length are to be determined to check the circularity of each connected component. A component is said to be circular if its *c* value given by equation 3 tends to 1.

$$c = abs(1 - \left[\frac{MajorAxisLength - MinorAxisLength}{\max(MajorAxisLength, MinorAxisLength} \right] \quad (3)$$

The result of differentiating microaneurysms from hemorrhage is demonstrated in figure 6.



a. b.

Figure 6. a: microaneurysms and b: hemorrhages.

3.0 Results

As mentioned above, the aim of this work is to develop a retinal screening system that can help early diagnose of retinal disorders to prevent blindness. Major steps in such system is to provide some means by which the abnormalities can be detected. Since we are interested in detecting the retinal abnormalities that can lead to blindness, we implemented some algorithms that can be used to accurately detect the exudates, microaneurysmss and hemorrhage as early signs of retinal disorders.

A new pre-processing algorithm based on subtracting high pass-filtered of the green component from the original one is proposed. The application of this algorithm to retinal images, enhances the appearance of the dark spots which represent the hemorrhage and microaneurysms in fundus photographs. As demonstrated in figure 2, the result of this pre-processing algorithm increases the accuracy of red lesion detection. This algorithm has been tried on our dataset and the best results of red lesion enhancement were obtained using values of 1 and 2 for the factor *a* which is the multiplication of the high-pass filtered image.

A combination of the morphological algorithms used for the detection of hemorrhage and microaneurysms is sued in this work to obtain more accurate results than that obtained previously. This resulted in increasing the sensitivity of red lesion detection in the fundus photographs.

Together with our previously published exudates detection algorithms, these algorithms are used in our proposed screening system. The system provides a computer program with a user-friendly interface that help physician in diagnosis and treatment planning. The system can capture fundus images from camers, process them and save them for further analysis and study. It also provides general image processing technique as enhancement and montage synthesis. A snapshot of the screening system is shown in figure 7. In this figure, the captured image can appear in the input frame. Many images from a video sequence can be taken and put into a montage to get the full extent of the human retina for better diagnosis and treatment planning. At the lower left of the figure, the processed retinal image are displayed. The first demonstrates the blood vessel tree as this is of great importance for the ophthalmologists. In the second image, the blood vessel tree, the optic disc and the macula are segmented for further investigation that can be done by the physicians. Lesions are detected and presented in different colors in the third image. Exudtaes appear as yellow structures where hemorrhage and microaneurysms are presented at different degrees of red color.

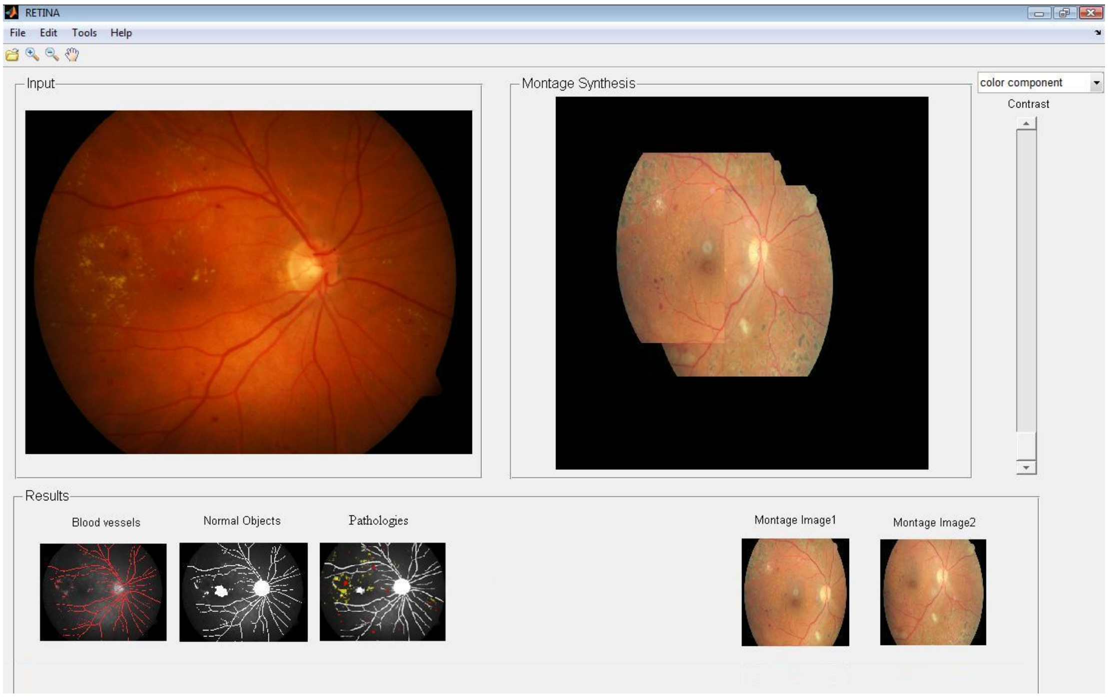


Figure 7. **a snap shot of the screening system.**

4.0 Conclusion

In conclusion, we provided a new image pre-processing techniques to selectively improve the detection of microaneurisms and hemorrhage as early signs of diabetic retinopathy. The technique is based on sharpening the image using high-pass filtering. Then, selective smoothing of the bright objects in relation to their background while increasing the contrast of the dark objects. This could be efficiently used to improve the detection of microaneurisms and hemorrhage in retinal images using common segmentation algorithms. The proposed method together with our previous work used to detect exudates in retinal images can be used to implement a screening system for the retinal diseases.

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