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Automatic Early Diagnosis of Diabetic Retinopathy Using Retina Fundus Images

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Abstract:

Diabetes affects a lot of people everywhere, and has associated complications such as vision loss, heart failure and stroke.

Among a group of 100 patients with diabetes, 10 people would likely have diabetes-related eye problems. An ophthalmologist (eye doctor) would have to check the eyes of all 100 patients periodically to find out who had problems.

The proposed system tend to analysis the retina fundus images for early detect of any sign related to eyes problems due to diabetic.
The image analysis system is broken down into a number of modules which sequentially process the input image to extract information at different levels.

These modules included detection the exudates and hemorrhage, blood vessel touristy measure, blood vessel diameter, and each of these modules may need another steps for analyzing of image.

The results were highly promised and the percentage of early detection for normal and abnormal retina was 100%.

Key words: diabetic, retina, exudates, blood vessel, fundus image, image processing, hemorrhage, touristy measure, retinopathy, blood vessel diameter.

1. Introduction

Diabetic complications lead to blindness in working age people [1]. The progressive death of the retina due to the loss of the blood supply results from effects of diabetes on the retinal blood vessel network, and the potential consequence of this for the eye [2]. The resulting visual loss brings significant costs, both to the individual and to society. Early ophthalmic intervention and constant monitoring is essential, with an estimated 90% of visual loss being avoidable if followed [3].

Diabetic retinopathy (DR) is a common retinal complication associated with diabetes [4]. It is a critical eye disease which can be regarded as manifestation of diabetes on the retina [1]. The retina is a multi-layered sensory tissue that lines the back of the eye. It contains millions of photoreceptors that capture light rays and convert them into electrical impulses. These impulses travel along the optic nerve to the brain where they are turned into images [5].

Diabetic retinopathy is characterized by the development of retinal micro-aneurysms, hemorrhages and exudates [4]. Micro-aneurysms are focal dilatations of retinal capillaries and appear as small round dark red dots. Hemorrhages occur when blood leaks from the retinal vessels [1].

Exudates are lipid leaks from blood vessels of abnormal retinas and are one of the most prevalent lesions at the early stages of diabetic retinopathy [6]. The bright circular region from where the blood vessels emanate is called the optic disk. The fovea defines the center of the retina, and is the region of highest visual acuity. The spatial distribution of exudates, micro-aneurysms and hemorrhages, especially in relation to the fovea can be used to determine the severity of diabetic retinopathy [4].

In 2010 Singh and Chandra presented a method to automated early detection of diabetic retinopathy using image analysis techniques. The automated diabetic retinopathy diagnosis system was thus used to various lesions of the retina i.e. exudates, microaneurysms, hemorrhages, their count size and location to assess the severity of the disease, so that the patient can be diagnosed early and referred to the specialist well in advance for further intervention [7].

In 2013 a retinal blood vessel segmentation method with optic disc pixels detection was presented by Wihandika and Suciati. Firstly, the segmentation of the retinal blood vessels was done using multi-scale line detector technique. Then, the pixels around the retinal optic disc were segmented. The resulting optic disc segmentation image was then used to subtract from the image obtained using the multi-scale line detector technique. The result was a blood vessels segmentation image which excludes false positive pixels around the optic disc [8].

In 2013 Li *et. al.*, introduced a new method which proposed to detect vascular bifurcations and crossovers in fundus images. The Gaussian filter is applied to the blue channel of the original color retinal images to suppress the central reflex and reduce the candidate points. The eigenvalues and eigenvectors of Hessian matrix are then obtained in multiple scales to provide the structural and directional information. By computing the anisotropy and isotropy of neighboring image segments for each pixel in a retinal image, they define a multi-scale vessel filter which combines the responses of tubular structures and the responses of bifurcations and crossovers [9].

2. Proposed Method

2.1 Preprocessing

2.1.1 Choose the best channel

Fundus image is an RGB color image, in general RGB images consist of three channels (red, green and blue) and this feature will investigated in this study for localization of the blood vessels. This can be accomplished by separation the retina image to three channels and using only one of them, the blue channel is characterized by low contrast and does not contain much information. The vessels are visible in the red channel but this channel usually contains too much noise or it is simply saturated, since most of the features emit a signal in the red channel. While the green component of the color retina image gives the best result in the contrast of blood vessels (darker blood vessels on a bright background). Therefore, the green channel of the image is used in the automated analysis of fundus images as shown in **Fig 1.**

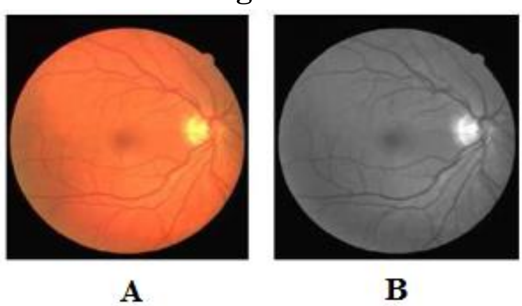


**Fig. 1: A) A typical color retinal image.
B) Green channel of image in A.**

2.1.2 Removing the background of retinal image

All the components in the green channel will be labeled by using image label algorithm illustrated in [10].

The area will be computed for all labeled regions in the green channel of retinal image, and then find the larger area among all labeled regions. Mark the borders of the largest region with white. The result shown in **Fig. 2.**

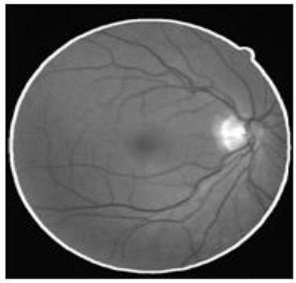


Fig. 2: retinal borders with white

The problems of the false detection of the contour in the retinal as blood vessels due to the presence of atrophy in the border of the retinal (There is a similarity between border of the retinal and blood vessels) will be resolved by removing the background for the resulted image in **Fig. 2.** by convert the background to white color (every pixel outside the white border changed to white color) as shown in **Fig. 3.**

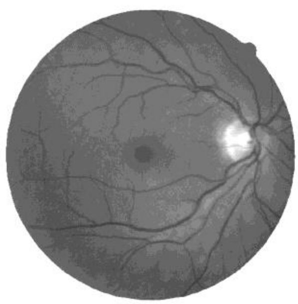


Fig. 3. Retinal image after removing the background

2.2 Image Enhancement

Retinal images after acquisition are generally noisy, low contrast and non-uniform illumination, and therefore some algorithms were applied to enhance image and noise reduction by increasing contrast and filtering.

A contrast-limited adaptive histogram equalization "CLAHE" was applied for contrast enhancement. "CLAHE" operates on small regions in the image. The contrast of each small region is enhanced with histogram equalization.

The techniques of "CLAHE" are well-known for their local contrast enhancement of the images and facilitate the task of many physicians before image analysis. Enhancement constitutes the first step towards automatic analysis of retinal images. "CLAHE" technique applied to the image after removing background, this make the image well contrasted as shown in **Fig. 4.**

After performing the equalizations, a Gaussian filtering operation was then applied to reduce noise, this step accomplished by two sub-steps, the first one is the filtering operation carried out by removing bright details smaller than a threshold (i.e., small bright details), by applying area opening, and the second step by applying a Gaussian filter (equation 1) for noise reduction:

$$G(x,y) = \frac{1}{2\pi\sigma^2}\exp\left(\frac{x^2+y^2}{\sigma^2}\right) \qquad \textbf{(1)}$$

Where x is the distance from the origin in the horizontal axis, y is the distance from the origin in the vertical axis, and σ is the standard deviation of the Gaussian distribution.

Application of combined the opening operation and Gaussian filter try to reduce all details that are not belonging to vessels but to some noise in the image. Filtering result is shown in **Fig. 4 (B).**

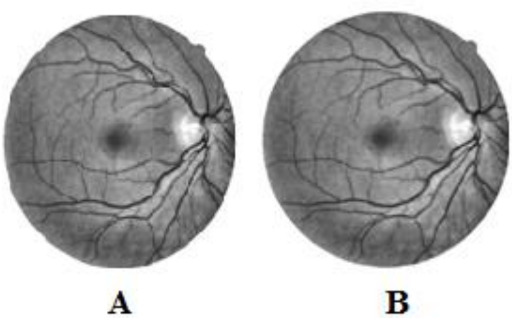


Fig. 4: Enhance and filtered images
A) Adaptive Histogram Equalization (AHE). B) Filtered image.

2.3 Analysis of Retinal Images

Automatic analysis of eye images is an important task whose objective is to assist ophthalmologists in the diagnosis of diseases such as diabetic retinopathy (DR) and age related macular degeneration, which are the main causes of blindness in several patients with these diseases. It is very important for ophthalmologists to determine these diseases in early stage because some of these diseases, if not detected early, can make people blind.

There are three anatomical structures visible in the retinal images:

- **the macula**, responsible for vision,
- **Optical disk,** causing the optic nerve.
- **Vascular network** composed of large dark blood vessels (veins) and small blood vessels (arteries).

2.4 Automatic Early Diagnosis of Diabetic Retinopathy using retinal fundus Images

There are many steps followed to diagnosis of DR, for each step one or more algorithm suggested. From the results of these algorithms, the DR will be estimated. The input image is retinal colored image as in **Fig. 5.**

Fig. 5. A typical colored retinal image.

2.4.1 Automatic Detection of Exudates in Retinal Images

Exudates are common abnormalities in the retina of diabetic patients. Exudates are bright lipids leaked from a blood vessels as shown in **Fig. 6**. The leaked fluid tends to stay close to the lesion, giving a generally well-defined edge suitable for computer analysis.

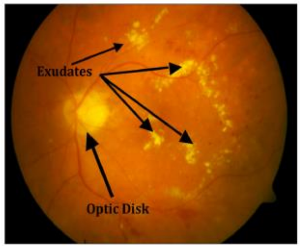


Fig. 6. Exudates and optic disk.

New methods are developed to localize and isolate the optic disk and detect the exudates. Algorithm is try to localize the optic disk and treat the confusion due to similarity between exudates and optic disk. The suggested algorithm use some of image features to separate exudates from physiological features in digital fundus images.

The goal of the paper is detection of the non-proliferative stage of DR which is exudates, so that the disease can be managed appropriately to decrease the chances of vision impairment.

Exudates detection faces some of problems that affect on the efficiency of any detecting algorithm. One of the major problems faces exudates detection is the color similarity between optic disc and exudates. Other thing is the recognition of false exudates.

It is an automated method for detection of bright lesions (exudates) in retinal images found in [10], the results of proposed method showed in **Fig. 7**.

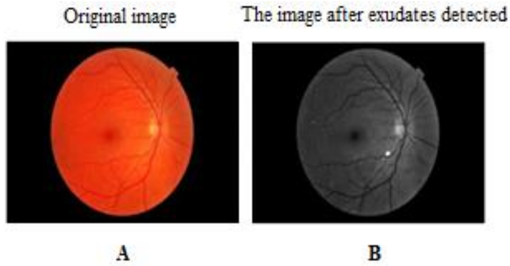


Fig. 7: A) Original retina image. (B) retina image with exudates detected

2.4.2 Automatic Bleeding Spots (Hemorrhage) Detection

Temporal to the optic nerve head is the macula, which appears darker in color and has no blood vessels present in the center. The fovea lies at the center of the macula and is the part of the retina that used for fine vision. Retinopathy in this area termed maculopathy is associated with a high risk of visual loss. The macula is a dark approximately circular area but the contrast often quit low and may be obscured, which can have a similar appearance to hemorrhages as shown in **Fig. 8**.

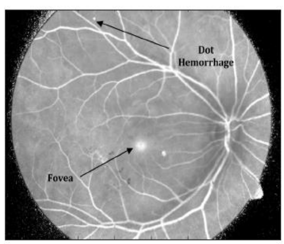


Fig. 8. Detection of the macula and fovea

This study introduced new method depending on the hemorrhage shape to detect the Dot Hemorrhage (DH), its number and size at early stage, this can be achieved by reducing the retinal image details. Detection and recognize the DH by following three sequential steps, removing the fovea, removing the vasculature and recognize DH by determining the circularity for all the objects in the image, finally determine the shape factor which is related to DH recognition, this stage strengthens the recognition process. The proposed method recognizes and separates all the DH.

The intensity plays an important role in the detection of dot hemorrhage, practically the “dark” part in retina image represented with low numbers in terms of intensities. The regions with high and low intensities in image may have very important features because it is marked as image objects. The first step of processing retain images is to reduce image details by converting color image to a gray scale image.

In an image of several objects, points of low intensity could represent the interested objects; this minimum intensity can be used to identify objects in an image. An image can have multiple low intensity, but only regions which has intensities smaller than or equal to threshold (12) (the band of red, dark and obscured region) and has similar texture determined.

This process converts the image to binary image by changing each pixel equal or smaller than threshold to white color with value 1, while the other pixel will change to black color with value zero. The threshold is determined by experiments.

At this case all the image details are changed to background as black color, while the white pixels represent the dot hemorrhage, fovea and parts of vasculature (parts of vasculature will be removed at this stage but not all).

The next step is to label all the components (regions) in the binary image by using image label algorithm, this accomplished by scans all the image pixels, assigning preliminary labels to nonzero pixels and recording label equivalences in a union-find table. Then, resolve the equivalence classes using the union-find algorithm (The Union-Find algorithm is used for maintaining a number of non-overlapping sets from a finite universe of elements). Finally, re-label the pixels based on the resolved equivalence classes.

The final step is to recognize the dot hemorrhage from the other similar objects, by using three sequence processes.

The proposed method illustrated in [11]. The result of this algorithm showed in **Fig. 9**.

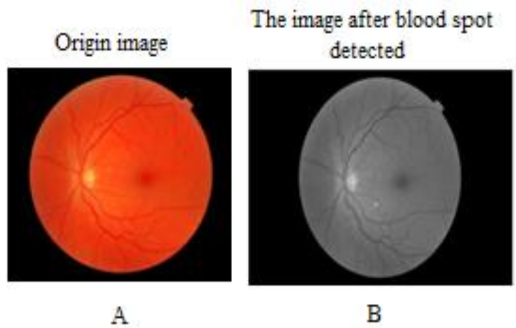


Fig. 9: (A) Origin image (B) Original retina image with bleeding spots detection

2.4.3 Blood Vessels Extraction

The retinal vasculature is composed of the arteries and veins with their tributaries, which are visible within the retinal image.

The segmentation and measurement of the retinal vasculature is of primary interest in the diagnosis and treatment of a number of systemic and ophthalmologic conditions. The accurate segmentation of the retinal blood vessels is often an essential prerequisite step in the identification of retinal anatomy and pathology.

The detection of blood vessels is a major problem in the automatic processing of retinal images. The vessels have certain properties, such as diameter and touristy, which may be regarded as the key indicators in the evolution of certain retinopathies.

The segmentation of blood vessels is the best technique to find the ridge lines in an image. In this case, ridge lines correspond to skeleton of blood vessels, where it is not necessary to extract the whole network but only to find the skeleton.

An automate approach was suggested for blood vessels extraction by using mathematical morphology. This operation of segmentation applied to binary image of top-hat transformation, the algorithm presented in [11], and the result showed in **Fig. 10**.

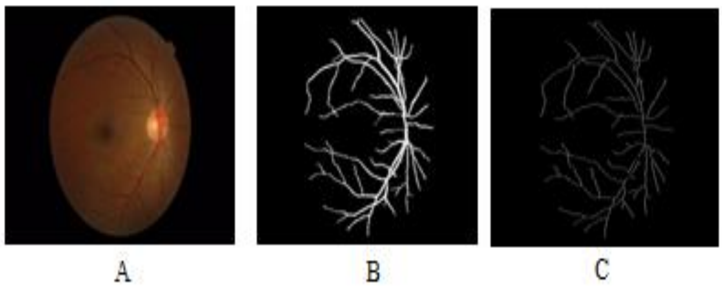


Fig. 10: A) A typical color retinal images. B) Blood vessel networks. C) thinning retinal networks.

2.4.4 Automatic Detection of Vascular Bifurcations and Crossovers

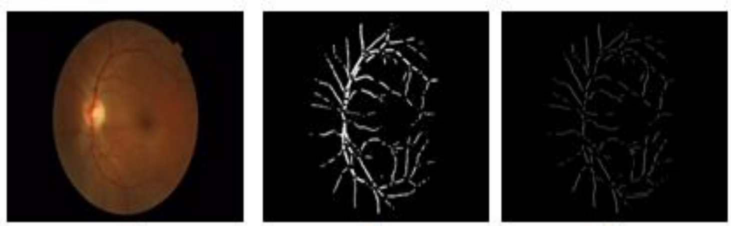
The bifurcations and crossovers are important feature points, which play important roles in the analysis of the retinal vessel tree. More than 100 vascular bifurcations can be seen in a typical retinal fundus image. Their manual detection by a human observer is a tedious and time consuming process. This paper attempts to automate the detection of retinal vascular bifurcations and crossovers points and removing it from the image.

The proposed algorithm attempts to automate the detection of retinal vascular bifurcations, crossovers points, and removing it from the image. A specific mask suggested to locating and recognizing the nodes and crossover points in retinal fundus image. The results of implementing this proposed algorithm was reliable and very accurate.

The algorithm is organized to determined and remove the areas that binds more than one blood vessel found in the retinal blood vessels network and the crossover points, using the novel metric proposed introduced in [13].

The first step in this algorithm is converting the input retinal fundus image to binary skeletonization image; skeletonization is performed by suggested algorithm which based on mathematical morphology [12].

The input is a skeleton image for the retinal image. A region of interest (ROI) containing the skeleton vessels. In skeleton image, the area that binds more than one blood vessel to be detecting and remove using a novel algorithm proposed. All subsequent operations take place with ROI. The output is segmented skeleton network image and segmented blood vessels network image as in **Fig. 11.**



A B C

Fig. 11: A) A typical color retinal image. B) Discrete Blood vessels network image. C) Discrete network image.

2.4.5 Automatic Retinal Vessel Tortuosity Measurement

Retinal vascular vessels have the role to indicate the retinal diseases and for systematic diseases when there are any abnormalities in retinal vascular pattern. A characteristic of the vascular pattern that is appreciated by clinicians is vascular tortuosity, i.e., how curved or kinked a blood vessel, either vein or artery, appears along its course.

We suggested a novel mask filter to track the blood vessel along its course and measuring the blood vessels tortuosity over the entire human retinal vessel network in fundus eye image, by using the arc to chord ratio. The suggested algorithm tested with straight and curve hand drawing lines and gives high accurate results.

We first perform binary skeletonisation for the human retinal vessels network in fundus eye image, and then this image will be thinning. After skeletonisation the terminal and branching nodes are then located and removed from the skeleton thinning network; skeletonisation and removing branching nods achieved by using algorithms suggested in the papers [12][13]. This will produce a number of Blood Vessels Segments. One of the major difficulties in tracing is tracing the vessels with high curvature, the difficulties results from the ambiguity of determine the high curvature as vessel branch or vessels tortuosity. Wrong tracers will produce fake tortuosity. The proposed algorithm expressed in [14], **Fig. 12** illustrate the results of proposed method.

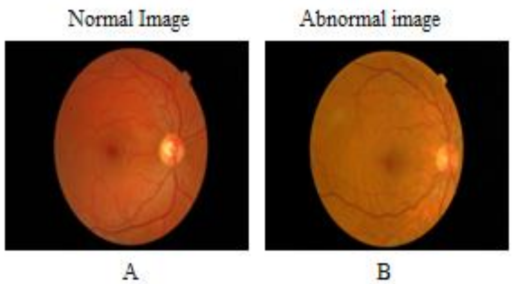


Fig. 12: A) Normal image. B) Abnormal image

2.4.6 Blood Vessel Diameter Measurement on Retinal Image

Accurate measurement of vessel diameters on retinal images plays an important part in diagnosing cardiovascular diseases and early signs of certain systemic diseases, such as diabetes and hypertension. In this study we developed new method based on computer aided to determine the width of retinal blood vessels by analyzing the color fundus image. Retinal vessel diameter was measured based on blood vessel wall estimating on the digital fundus image.

First step in this algorithm is to localize and remove the nodes in the origin retinal binary image using the previous techniques. All these nodes will be removed by changing the value of pixels around the nodes coordinates to zero value (black).

The diameter or width of blood vessel at a point in a binary image is defined as the shortest line segment (Euclidean distance) passing between two edges (blood vessel wall), points (A and B) as shown in **Fig. 13**.

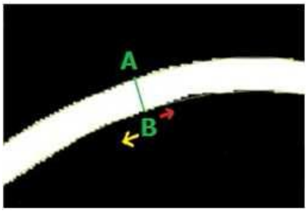


Fig. 13: Vessel width estimated between A and B

We suggested a dependable and accurate technique to determine the diameter (width) of retinal blood vessel based on suggested mask created to use specifically on measuring the blood vessel diameter. The suggested system starts by removing the bifurcations and determine the width for each blood vessel segment.

A reliable and accurate method to measure the width of retinal blood vessel in fundus image is proposed in [15], **Fig. 14** illustrate the results of proposed method.

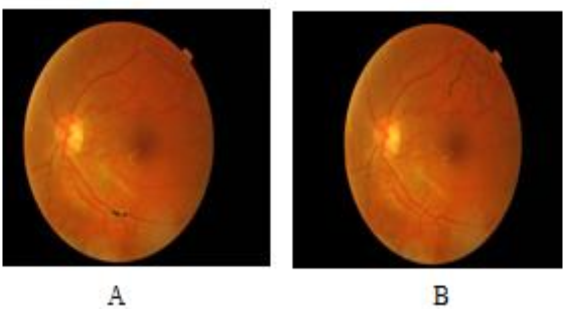


Fig. 14: abnormal image (colored image) A) Increased diameter of main vessel. B) Increased diameter of branch vessel.

3. Results and Performance Measures

The developed algorithms were tested and evaluated with (235) color fundus images, (200) taken from 12 separated tested sets, each set of which contain of (100) color fundus image from

Messidor database, (25) fundus image taken from **Diaretdb1 database**, and (10) fundus image taken from **al-Hilla teaching hospital** in Hilla province/ Iraq.

Results, performance measures and time required for each step in proposed algorithms of automatic early diagnosis of diabetic retinopathy algorithm is illustrated in **Table 1**.

3.1 Automatic Early Diagnosis of Diabetic Retinopathy using eye Images

The proposed algorithms of automatic early diagnosis of diabetic retinopathy in retinal images accurately detected the presence of any abnormalities may affect the eye due to diabetic with sensitivity of (100%), specificity of (100%), accuracy of (100%) and precision of (100%). The sensitivity, specificity and accuracy values are shown in **Tables 2, 3, 4, and 5**.

Table 1: Results, Performance measures and time of automatic early diagnosis of diabetic retinopathy algorithm.

Algorithm type	**Result of Algorithm**	**Performance Measures**		**Average Time Seconds**
Automatic detection of exudates	Detection of exudates	Sensitivity	97.7%	5
		Specificity	100%	
		Accuracy	100%	
		Precision	98.7%	
Automatic bleeding spots detection	Bleeding spots detection	Sensitivity	100%	10
		Specificity	100%	
		Accuracy	100%	
		Precision	100%	
Blood vessels extraction	Segmentation of blood vessels network	PSNR	13.1999	154
Automatic detection of vascular bifurcations and crossovers	Segmented blood vessels network	Average Performance	98.192%	0.7

Automatic retinal vessel tortuosity measurement	Retinal vessel tortuosity measurement	Prediction	100%	21
Blood vessel diameter measurement	Measurement of blood vessel diameter	Accuracy	98%	341
Prediction Algorithm	Automatic early diagnosis of diabetic retinopathy	Sensitivity	100%	480 as maximum
		Specificity	100%	
		Accuracy	100%	
		Precision	100%	

Table 2: Result sensitivity percentages

T_p	F_N	**Sensitivity %**
135	0	100

Table 3: Result specificity percentages

T_N	F_P	**Specificity %**
100	0	100

Table 4: Result Precision percentages

T_p	F_p	**Precision %**
135	0	100

Table 5: Result accuracy percentages

T_N	T_P	F_N	F_P	**Accuracy %**
100	135	0	0	100

Where $\mathbf{T_N}$ is true negative, $\mathbf{T_P}$ is true positive, $\mathbf{F_N}$ is false negative, and $\mathbf{F_P}$ is false positive.

In summary, the algorithms shows excellent potential for detecting the diabetic retinopathy.

3.2 Execution time of proposed algorithm

The execution time of proposed algorithm required to classify each input eye image as normal or abnormal is illustrated in **Tables 6 and 7**.

Table 6: Time of *normal images* in minutes

Image No.	Time
1	8
2	8
3	5
4	8
5	7
6	6
7	7
8	5
9	6
10	8

Table 7: Time of *abnormal images* in seconds

Image No.	Time
1	5
2	6
3	4
4	5
5	4
6	5
7	4
8	6
9	5
10	5

Tables 6 and 7 shows that the time required for classify image as abnormal image is less than the normal image. This is because the normal input image checked with all suggested algorithms to indicate any sign for diabetic retinopathy (which are exudates detection algorithm, bleeding spots detection algorithm, compute blood vessels diameter algorithm and compute blood vessels tortuosity algorithm) and this took long time than the abnormal input image which stop checking when any sign indicates by any algorithm.

The time measurement of the above tables are shown in **Fig. 15**.

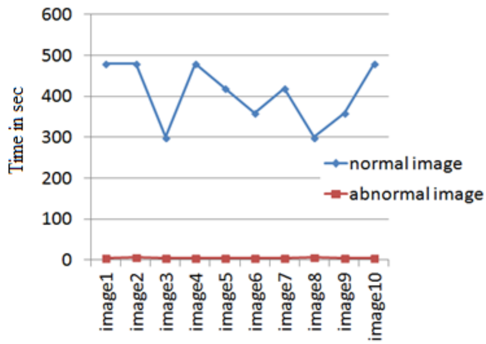


Fig. 15: The time needed for detecting normal and abnormal images in sec.

In summary from tables 6 and 7 the average execution time of the proposed algorithm for the classification each input image as normal or abnormal is about 8 min as maximum.

4. Conclusions

This method investigates many suggested algorithms to test the early effects of diabetic on retina, which make the results very accurate.

The other methods almost depend on one or two signs for detection of diabetic retinopathy, while in the current proposed algorithm we investigate all the possible signs that may occurs when the retina infected with diabetic retinopathy (which are exudates detection, bleeding spots detection, change on blood vessels diameter and change on blood vessels tortuosity).

Most of the other methods detect diabetic retinopathy on late stages, while the current method predicates diabetic retinopathy in the early stage.

The execution time of proposed method required for classification each input image as normal or abnormal is 8 min as maximum.

One of the best benefits of this study is reducing the total times need to examining the patients, because the suggested method simple and fast and doesn't need more time comparing with other previous methods.

The results for the proposed method, has sensitivity of (100%), specificity of (100%), accuracy of (100%) and precision of (100%). According to this results the accuracy of this method in recognition of diabetic retinopathy in early stage up to 100%.

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