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AUTOMATIC SEGMENTATION OF BLOOD VESSELS (ASBV) OF RETINAL FUNDUS IMAGES USING CLAHE AND MULTILEVEL THRESHOLDING BASED ON HARMONY SEARCH

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ABSTRACT

The main objective of the medical image-processing field is to design computational tools that will assist the quantification and visualization of remarkable pathology and anatomical structure. Diabetic retinopathy is a medical disorder where the retina is damaged due to fluids leak from the blood vessels into the retina of the human eye. The identification of blood vessels in retinal fundus images and quantitative study of the evolution of its shape and size plays an important role in diagnosing different abnormal conditions correlated to the retinal structure of the human eye. Most of the abnormalities, which relate to blood vessels, may tend to a structural change of the blood vessels. Segmentation of blood vessels corresponding to entire retinal image reduces the sensitivity for those areas. In this research, an advanced algorithm related to CLAHE and multilevel thresholding based on harmony search for the detection and segmentation of blood vessels has been proposed. The presented technique helps to reduce the process area needed for segmentation method related to notable performance enhancement and reducing computational cost for each fundus image of human eye. The proposed technique has been evaluated on publicly available data sets of retinal images, which are CHASEDB1, DRIVE, HRF and STARE, and a remarkable improvement has been found over the existing techniques in terms of accuracy and processing time.

KEYWORDS

Retinal image analysis, Region-of-Interest, CLAHE, blood vessels, multilevel thresholding, harmony search, segmentation and classification.

1. INTRODUCTION

Diabetes associated with different serious complications to human organs such as heart failure, complete vision loss, types of strokes, etc., is more likely to develop different problems related to the eye such as glaucoma and cataract but the effect of diabetes on the retinal system causes the main risk in vision system that may cause different complications in retina including complete vision loss is called diabetes retinopathy (Niladri et al., 2020; Susman et al., 1982).

Ophthalmologists diagnose several eye-related diseases by using the retinal images, which captured by the fundus camera with different settings of the camera. Analysis of retinal images includes the identification and extraction of many retinal anatomical structures, which directly related to the disease. There are several examples of retinal structures are shown in the following figure 1 that depicts the target features for different segmentation techniques such as Retinal optic disc, optic cup, vessels, fovea, exudates, hemorrhages, etc. (Almotiri et al., 2018; Srinidhi et al., 2017; Almazroa et al., 2015; Fraz et al., 2012).

In this research, authors are precisely focusing on the outcome of diabetes on retinal vessel structures of the human eye. Blood vessel diameter changes due to the change in vessel fluid pressure, which relates to the sugar level of the human body. Generally, in retinal image optic disc is the brightest part where the blood vessels are merging. Optic disc identification can be used to identify the blood vessels.

Figure 1: Different features of retinal images of human eye related to diabetes. Source (Joshi et al., 2011).

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According to more than 382 million people (age 40 to 59 years) are suffering from diabetes disease (Aguiree et al., 2013; Wild et al., 2004; Bottomley et al., 2008). While India, USA, and China are considered as the top with respect to other countries and for screening this kind of large population, a very large no of the ophthalmologist is primarily needed. For this, it is very much essential to design an algorithm to detect diabetic retinopathy automatically. This research presents an advanced technique for the fast and accurate segmentation of retinal vessels in different special filtering; contrast limited advanced histogram equalization and multilevel thresholding technique based on harmony search.

First, the optic disc has been identified after that segmented from the fundus image. The red component of the input image has considered as it provides the brighter part of the image more clearly. Special filters remove unwanted frequency components from the applied signal and enhance wanted ones. Histogram of the red part of the input fundus image provides different intensity characteristics. Most of the images with the highest intensity has considered as the optic disc. The different morphological technique has been used to segment out the optic disc. Secondly, the image has been enhanced so that the vessels can be found more clearly. CLAHE with different clip limits has been used to achieve the best-enhanced result. Finally, multilevel thresholding based on harmony search has been introduced to segment out the vessel structure. After the experimental evaluation, it is observed that the proposed technique shows better results in terms of image contrast, illumination, and quantitative performance and is computationally faster in terms of processing.

2. LITERATURE REVIEW

There are different kinds of work that have been done related to this field, some of the work have discussed below. In the author deeply researches on the advanced classification of optic disc for the segmentation and detection of vessels based on the hierarchical process (Niladri et al., 2020). Here an innovative morphological based thresholding technique is implemented for exacting the boundary of the optic disc. The proposed technique is very much helpful to reduce the process area for the vessel segmentation techniques. For this, the computational cost for each retinal fundus image is reduced. After the experiment, it is observed that the proposed technique shows a better result in terms of accuracy and processing time.

In the author compares the OTSU thresholding with Morphology based thresholding for the segmentation of vessels (Niladri et al., 2016). Generally, threshold segmentation is an important step for image segmentation and it has a lot of scopes available on the research field of image processing of this technique. The thresholding is the simplest method of image processing to separate any object from the background image. Here two different techniques are applied for the vessel segmentation and after the experiment; it is observed Morphology gives a better result than the OTSU thresholding for the segmentation of vessels.

In the author proposed a concept of blood vessel segmentation of the retinal image (Rattathanapad et al., 2012). In this paper, the author exhibits the technique of line detection in the multi-scale framework for vessel segmentation with systematically combines the Gaussian line detection output, which sequentially applied to the input. The Blood vessels of a retinal image are very much an important factor for the diagnosis of different types of diseases such as diabetes, arteriosclerosis, and hypertension. Normally, the images, which are taken from the retinal cameras, are usually poorly contrasted. To detect the diseases from that image, the ophthalmologist takes a lot of time. For making, the process in the easiest way multiple algorithms developed to segment blood vessels of the retinal images.

Various changes in morphology, branching, diameter, the pattern of blood vessels indicate various clinical disorders of body and eye. In the author

discusses the vessel segmentation of retinal images by using the supervised method (Fraz et al., 2012). For the classification of the retinal image in this work, a Bayesian classifier has been used.

Blood vessel segmentation of the retinal fundus image is the initial step for the detection of different types of diseases, which related to retina such as diabetic retinopathy. The retinal fundus image of the patients shows some abnormalities, which predict the presence of diseases (NehaGour et al., 2017). In another paper, the author proposed an efficient method for the segmentation of vessels with the help of morphological top-hat transformation by using the hybrid median filter. In this paper, the method evaluated in terms of the accuracy of the segmentation, specificity, and sensitivity.

In another paper the author proposed the method for blood vessel segmentation of retinal images (SaeidFazli et al., 2013). The structure of blood vessels of retinal images is a very much important factor in terms of the diagnosis of different kinds of diseases. Here, the author proposed a scheme on the preprocessing of the retinal image by enhancing the histogram of the images. In this paper, the author discusses the effect of the non-linear and linear intensity transformation in segmented vessels of the retinal image. Here the author focuses mainly on two methods for the segmentation of a vessel that includes the Gaussian matched filter and the first derivative of Gaussian matched filter. These methods are helpful in many research works but still, there are some problems, which may occur during the detection of vessels (Chaudhuri et al., 1989; Hoover et al., 2000; Al-Rawi et al., 2007; Bob et al., 2010). To overcome this problem adaptive histogram equalization technique is used. In this experiment, the improved match filter shows better results of accuracy.

The most important factor to manage the different diseases is the automatic detection of the structures of the blood vessel. In another paper [20] the author proposes an algorithm for the segmentation in retinal images based on the features of the integral channel. Here, a preprocessing technique performed for obtaining the pixels of vessels of each candidate.

3. PROPOSED SCHEME

In this research, a novel supervised method has proposed for the segmentation of the vessel to detect the retinal abnormalities. Generally, the optic disc is the brightest section of the retinal image but the total section of the optic disc is not equally bright. Therefore, for the detection of the optic disc boundary efficiently, it is very much essential to detect the total brightest part of the optic disc. To achieve an effective result a six steps approach has proposed in this paper. At the first stage of this technique all, the retinal images collected from different sources, which are publically available. The second stage related to the filtering technique and enhancement of vessels. To achieve this median filter plays a very vital role in removing the noise from the input image. After that, the Contrast Limited Adaptive Histogram Equalization (CLAHE) technique is applied to those images for the enhancement of vessels. In the third stage of the scheme, Morphological opening and Top-Hat operation performed. After that, in the fourth stage Multilevel Thresholding technique is applied to detect the major blood vessels. The fifth stage includes the morphology-based operation to detect the specific edges and shapes in the image and in the final step image analysis done for the detection of segmented vessels from the retinal images.

Figure 2: Proposed System Architecture

3.1 Data set of Retinal fundus image:

For the segmentation of the input fundus image, all the retinal images marked manually by using GIMP software. The proposed scheme examined on the fundus images collected from the publically available data set.

DRIVE contains a data set of 40 TIFF images taken by the CANON CR5 fundus camera with the 45 fields of view and the pixel size is pixel size 584564 (Zhang and Zhao, 2014). This dataset contains 40 images among them 7 images are diseased image and rest part is normal. In another data set, DIARETDB1 consists of 89 PNG images captured by the Nikon F5 fundus camera with the 50 fields of view and the pixel size is 11521500. This dataset contains 89 images among them 84 images are diseased image and rest part is normal. In STARE data set there are 81 TIFF images taken by TopCon TRV-50 fundus camera with the 35 fields of view and the pixel size is 400600. This dataset contains 81 images among them 50 images are diseased image and rest part is normal. In DRIVES-DB data set there are 110 JPEG images with the pixel size is 600400 and in Madrid, data set there are 597 images with the pixel size 28484288.

For smoothing the image here median filter is used as it is an effective solution for smoothing the image as it is very much efficient to reduce the noise and preserve the information about the edge of the resultant image (Niladri et al., 2013). It also does not create any unrealistic pixel intensity.

3.2 Median Filter

The Median filter is used to remove the noise from the input figure after the top-hat transform technique. Generally, the median filter used as a quality improvement process in the spatial domain. In the Median filter, pixel values are sort in the upward window for smoothing the image and remove the noise. After the sorting process, the median values obtain the original pixel value at the center of the window. During the process, if the pixel sequence is even, then, in that case, the average of two middle pixel values are taken for the future work. The mathematical equation for the median filter given below.

$$f(x, y) = \text{median}[g(a, b) | (a, b) \in W] \quad (1)$$

Working function:

Take the 3×3 windows and check the fifth pixel and if the pixel is noisy then in that case the pixel value replaced with the median value. After that, the diagonal pixel value selected from window for checking if the diagonal window is noisy or not. Finally, after the checking, if it is found noisy, then in that case, the values replaced with the median value. In the same way, the horizontal and vertical pixel values are check and if it is found noisy then the horizontal and vertical pixel values are replaced by median values of the element.

3.3 Contrast Limited Adaptive Histogram Equalization (CLAHE):

For the vessel segmentation, image enhancement is an important step to increase the quality of the image and improved comprehension ability. Histogram equalization is one of the important techniques for contrast enhancement that will increase the intensity of the pixel for the proper utilization of the entire dynamic range. From the histogram, it is observed that the input fundus images have a low contrast value which is narrow and are only concentrates on a certain amount of gray level. Generally, it is very much difficult to observe every detail from the retinal image, which may cause delayed diagnosis or even the wrong diagnosis of diseases. To avoid this kind of situation histogram equalization plays a very important role. In this work, the CLAHE technique is implemented which is an efficient technique for the biomedical image. This technique is very much helpful to increase the background in-homogeneities. We proposed an image enhancement technique, which is based on the CLAHE method to divide the image into small contextual segments (Tiles).

CLAHE is one of the effective methods for the contrast enhancement to

overcome the problem of low contrast value in the digital images (Example Medical images). Generally, it is the advanced version of the Adaptive Histogram Equalization and Histogram Equalization technique for the probability of a grayscale image. In CLAHE, a patch is used to process the input retinal fundus image to get a better contrast value (Sahu et al., 2018). In this process, the contrast of each small area of the image (tiles) increases the histogram of the image. After that, the neighbouring tiles merged to avoid the induced boundaries. The contrast enhancement technique mainly used to avoid the noise of the image. Let the Histogram equalization technique is applied on image y and j is the value of the gray level. Here the probability of the image at j level can calculate $asp_y(j) = p_{(y=j)} = \frac{n_j}{n}$ (where $0 \leq j < L$) (2)

In the above image, the total number of gray level is L (generally, $L = 256$) and n is termed as total number of image pixels.

3.4 Morphological Processing

Generally, in image processing is the most suitable and acceptable technique to detect the shapes in images. For this Morphology is one of the efficient techniques which is introduced by Matheron to analyze the geometric structure of geologic and metallic samples (Serra et al., 1982). For the analysis of any image, mathematical morphology is a nonlinear tool, which plays a very important role in terms of quantifying the retinal pathology. There are four important steps of morphological operation such as Morphological Opening, Morphological Closing, dilation, and erosion (NehaGour et al., 2017). Generally, the morphological operation opening is the form of erosion, which followed by the dilation used for erasing any object and has a smaller size than the structuring element from the input image. So, for the enhancement of any object, which erased by using the operation opening, can be easily obtained by doing the operation between the original image and opened image (Fraz et al., 2011). The main assumption from the proposed scheme is that the vessels are the brightest part with the Gaussian shape cross-section when the background is dark, which piecewise connected with each other, and are generally linear in nature. Therefore, for the enhancement of the vessels from the input retinal figure the morphological filters used with the linear structuring element. Generally, the morphological opening operation oriented at a particular point, which remove the vessel or a particular part of the vessel when the vessel does not contain the structuring element due to the orthogonal directions of structuring element and vessel and the structuring element size is longer than the vessel width. On the other hand, the vessel will almost unchanged, when the orientation of structuring element is parallel with the vessel of retinal fundus image.

In the morphological process Dilation, the input image is superimposed by the Structuring Element. The main purpose of the Dilation operation is to increase the size of the pixels of the original image. It is also very much useful to fill the gaps in the image.

$$\epsilon_B(A) = \max_{(f,k \in B)} [A_{(m+f,n+k)} + B_{(f,k)}] \quad (3)$$

Like the Dilation, Erosion is another important morphological operation in which the main image is thinned by subtracting the main image by using the Structuring Element. It is the shrinking operation where the Structuring Element superimposed on the original image. In this technique, the resultant central pixel values are taken and the image details, which are smaller than the structuring element, removed from the main image.

$$\delta_B(A) = \min_{(f,k \in B)} [A_{(m-f,n-k)} - B_{(f,k)}] \quad (4)$$

The morphological opening consists of Erosion, which followed by the Dilation. This technique is used for the smoothing of the image, break the narrow joint, and remove the thin protrusions.

$$\gamma_B(A) = \epsilon_B[\delta_B(A)] \quad (5)$$

The morphological closing operation consists of Dilation, which is followed by Erosion. This technique is very much helpful for smoothing

the image by fusing the narrow breaks and removes the small holes.

$$\emptyset_B(A) = \delta_B[\epsilon_B(A)] \quad (6)$$

Another technique of morphology can be used for better extraction and remove the noise from the input fundus image known as morphological top-hat to get more details of the vessels from the input retinal image.

3.4.1 Morphological Top Hat

The morphological top-hat transformation used for extracting the brighter regions from the input image. Basically, top-hat transformation is the difference between the original image and its opening (Dalwinder et al., 2014). The top-hat transformation classified into two categories one is black top-hat transformation and another one is white top-hat transformation (NehaGour et al., 2017). In black top-hat, the objects are selected from the input image which has a smaller size with respect to the structuring element and also darker than the background. Generally, the blood vessels of the green channel are usually darker. For this, in this work, black top-hat is very much efficient. The equation of top-hat is written below.

$$T_H = A - \gamma_B(A) \quad (7)$$

3.5 Multilevel Thresholding

In the multilevel thresholding technique, several numbers of thresholds points such as $[Th_1, Th_2, Th_3, \dots, Th_L]$ have been used in the histogram image $f(x, y)$ to separate each image pixel. By using the separated threshold points, the original cropped image is being segmented to get the image $Th(f(x, y))$. Specifically:

$$T(f(x, y)) = \begin{cases} G_0 & \text{if } f(x, y) \leq Th_1 \\ G_1 & \text{if } Th_1 < f(x, y) \leq Th_2 \\ \dots & \dots \\ G_L & \text{if } f(x, y) > Th_L \end{cases} \quad (8)$$

Such that G_i denotes the gray-level allocated to all pixel points at the region i that eventually signifies the object i . As in equation, the $L+1$ areas are calculated by the L number of thresholds $[Th_1, Th_2, Th_3, \dots, Th_L]$. The maximum values of gray-level i.e. 255 can be used to dispense the gray-level regions correspondingly. Precisely $G_i = i \left\lceil \frac{255}{L} \right\rceil$, for this, an integer value of the argument is returned by the function. The value can be selected as the mean of gray levels of the pixels.

Performance Analysis:

Here true positive (TP) denotes the segmentation of vessel pixel as the vessel pixel on the other hand true negative (TN) denotes the segmentation of vessel pixel as the non-vessel pixel. In the same way, false positive (FP) indicates the non-vessel pixels segmentation of vessel pixels on the other hand false negative (FN) denotes the correct segmentation of vessel pixels as the non-vessel pixels.

The sensitivity, specificity, accuracy and the overlapping ratio for the output result found using the proposed method has been calculated using the below mentioned simple mathematical expressions:

$$Sensitivity = \frac{\Sigma \text{correctly classified foreground pixels}}{\Sigma \text{foreground pixels in groundtruth}} \quad (9)$$

$$Specificity = \frac{\Sigma \text{correctly classified background pixels}}{\Sigma \text{background pixels in groundtruth}} \quad (10)$$

$$Accuracy = \frac{\Sigma \text{correctly classified pixels}}{\text{total number pixels in groundtruth}} \quad (11)$$

$$Overlapping \text{ Ratio} = \frac{ODB_G \cap ODB_R}{ODB_G \cup ODB_R} \quad (12)$$

where, $ODB_G = \text{Optic Disc Boundary from groundtruth}$
 $ODB_R = \text{Resultant Optic Disc Boundary}$

The AUC is the area under the curve of the receiver operating characteristic (ROC) that shows the segmentation performance and determined by the combination of both the specificity and sensitivity. In this study, AUC calculated by using the following formula:

$$AUC = \frac{Sensitivity + Specificity}{2} \quad (13)$$

It should always remember that an AUC with a value of 0.50 or less than to it for this it can be stated that it is not very much useful as the segmentation is purely based on random guessing. On the other hand, an AUC with a value of 1.0 indicates that using the segmentation algorithm all the pixels can easily be segmented.

4. RESULT AND DISCUSSION

In this part of the research, the experimental results obtained by using the proposed method have been explored and discussed. The above-mentioned system has been developed and tested under MATLAB 2018a software with the help of image processing toolbox.

The proposed method for segmentation of vessel structure has been extensively tested on the above-mentioned publicly available databases. The choice of successful detection and failed detection of vessel structure is based on the observation of the human eye. To verify the results, vessels of each image are manually categorized by the ophthalmologists. The manually separated vessel structure by the human observer is considered as the ground truth data set. The proposed method has been used to detect the vessel structure automatically. Validation of the result set has been done by comparing it with the ground truth data.

To automatically identify the vessel structure, first pre-processing has been done to enhance the given fundus image of the human eye. As a first step of pre-processing, the green components of input RGB fundus image of the human eye has been considered as it gives the best-fitted result in the contrast of blood vessels (darker blood vessels on a brighter background). Next, a 3×3 median filter has been used to remove noise like salt and pepper noises. Finally, the CLAHE (contrast limited adaptive histogram equalization) technique is implemented for better enhancement of the image. The result set of CLAHE for different limits has been shown in figure (3) which an image data is taken from DRIVE.

Figure 3: Result shows the contrast limited adaptive histogram equalization on DRIVE data (04_test.tif)

In the post-processing part, the enhanced results found from CLAHE have processed through the morphological top-hat transform technique with the help of the structuring elements to extract the small elements and details from the given input images. The result is shown in the following figure (4).

Figure 4: Result shows morphological Top-hat transformation of DRIVE (04_test.tif)

In multilevel thresholding with the help of harmony search, best fitted five different intensity levels of the top hat transformed image are being calculated and shown into the different threshold. The fitness graph comparing the gray levels with probability is shown in figure (5). After multilevel thresholding morphological dilation and erosion are being used simultaneously to remove the unwanted variables and finally morphological closing is used to get the final result.

Figure 5: The result shows the fitness graph of multilevel thresholding comparing the gray levels with probability values

Figure 6: Result shows the outputs of DRIVE_04_test.tif: (a) input retinal fundus image (RGB), (b) Green components of the RGB image of retina, (c) result after using contrast limited adaptive histogram equalization technique with the limit 0.1, (d) morphological Top hat, (e) Multilevel thresholding using harmony search, (e1) Threshold limit of multilevel thresholding, (f) segmented vessels.

The segmented results compared to respective ground truth results using the mentioned different datasets are shown in figure (7). Table (1) shows the result of the performance analysis of the proposed technique compare to the previously established methods.

Figure 7: Result shows the images of segmented vessels (a) ground truth result, (b) automatic segmented result using proposed method.

Table 1: The performance analysis result of the proposed technique with compare to the previously established methods

Algorithm	Dataset	Number of samples taken	Sensitivity (SE) (%)	Specificity (SP) (%)	Accuracy (ACC) (%)	Overlapping Ratio (%)	AUC
SaeidFazli et al. [14]	DRIVE	40	-	-	93.53	-	-
Zhun Fan et al. [20]	DRIVE	20	71.9	98.5	96.1	-	-
	STARE	20	70	97.9	95.9	-	-
ASBV	DRIVE	40	99.63	96.69	97.00	98.73	98.16
	STARE	81	98.53	96.45	97.33	98.07	97.49
	HRF	15	99.71	97.62	98.22	98.79	98.66
	CHASEDB1	28	98.47	95.31	98.11	96.28	96.89
Ming Li et al. [19]	DRIVE	40	83.47	97.96	95.10	-	97.92
	STARE	20	82.31	97.82	95.60	-	97.43
Yitian Zhao et al [30]	DRIVE	40	77.4	97.9	95.8	-	97.5
	STARE	20	78.8	97.6	95.7	-	95.9
	HRF	45	74.9	94.2	94.1	-	97.1

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