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Automated Blood Vessels Segmentation Method for Retinal Fundus Image Based on Mathematical Morphology Operations and Kirsch's Template

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Abstract- Automated retinal Blood vessels analysis is currently a highly important tool and inevitable step in development of computerized systems in medical imaging field. Assessing the structure and appearance of the retinal blood vessels in retinal fundus image plays a significant role in diagnostic, screening, evaluation and treatment of many ophthalmologic conditions and diseases such as diabetic retinopathy, hypertensive retinopathy, glaucoma, and age related macular degeneration. In this paper, we present blood vessels segmentation approach, which can be used in computer based retinal image analysis to extract retinal blood vessels network. This method is conducted in 3 phases: 1) Pre-processing, where the retinal color fundus image is converted to grayscale image and enhanced using Contrast Limited Adaptive Histogram Equalization, 2) Extraction of retinal blood vessels using morphological operations and Kirsch's template, and finally, 3) Post-processing carried out using 2D median filter to remove noise and isolated pixels. Furthermore, the performance of the proposed algorithm is tested and analyzed on DRIVE dataset and compared with other existing standard methods using a number of measures like accuracy, sensitivity, specificity and time required to process a single image. We achieved 94.60% accuracy, 74.91% sensitivity, and 96.49% specificity; which are higher than many of the state of the art methods compared with. The proposed segmentation approach is also very efficient with time complexity that is significantly lower than the existing methods.

Keywords- *Image Processing, Retinal Blood Vessels, Morphological Operation, Kirsch's Template*

1. Introduction

Image segmentation is an important and useful technology for image processing. It consists of partitioning or subdividing a digital image into multiple segments (sets of pixels) containing meaningful information easier to analyze [1]. Image segmentation technology is widely used in different fields including healthcare [2, 3]; objects detection and pattern recognition [4], traffic surveillance systems [5], among others.

In the modern healthcare industry, image segmentation has become one of the important tools attracting several research interests focused on computation of accurate anatomy structure geometrical models in order to enhance automated early diseases diagnosis [6].

In ophthalmology, image segmentation has been reported to help in detecting different diseases and conditions such as diabetes retinopathy, hypertension retinopathy, glaucoma, age-related macular degeneration, and neovascularization and vein occlusion. This has been achieved by comparing changes in the state and delineation of morphological attributes of retinal blood vessels such as color, length, reflectivity, tortuosity, abnormal branching and occurrence of vessels of a certain width [7]. However, the retinal image information, usually collected manually, is very essential but challenging to obtain due to the long time required obtaining the information and human errors caused by low skilled physicians [8]. Therefore, several automatic techniques categorized as matched filtering based technique, tracking/tracing based technique, supervised based technique, unsupervised based technique, and mathematical morphology operations based technique, have been developed for the extraction of blood vessels [9].

2. Literature Review of Retinal Blood Vessels Segmentation

Many works have been done in the area of retinal color fundus image segmentation by using different techniques. Many techniques have been done to support completely different applications of image segmentation.

To improve flexibility in detecting blood vessels contours, Fabiola et al. developed a matched filtering technique in conjugation with entropy-based adaptive thresholding [10]. Thitiporn and Guoliang followed the same procedure proposed by Fabiola et al. for extracting both retinal vessels and optic disk [11]. Nagendra et al. applied the same procedure proposed by Fabiola et al., Thitiporn and Guoliang with standard Gaussian shaped matched filter modifications for identifying thin blood vessels together with large blood vessels [12].

Changhua et al. proposed the concept of vessel tracing method for retinal vasculature structure extraction which involved tracing the vessels via their Center lines along the ridges seeds after coupling Hessian and Matched filters [13]. On the other hand, Tamir and Richard traced the retinal vessels centers through Kalman filters to detect the wide and thin vessels in the noisy image [14].

The supervised based method introduced by Petar Sekulic et al. proposed for retinal blood vessels segmentation using SVM (Support Vector Machine) classifier with a characteristic line detector to detect retinal blood vessels [15]. In another study, Xu and Luo applied a novel method using local threshold and iterative linear extrapolation to overcome variation in contrast between large and thin vessels [16]. An algorithm was elaborated for vascular tree segmentation using back propagation multilayer neural network to recognize common features on the fundus image [17]. To address both retinal and optical disk segmentation, specialized trained layer of convolutional, neural network was recommended [18].

A method based on performing segmentation without any prior labeling knowledge [19], known as unsupervised method was proposed by Nogol Memari et al. to segment retinal blood vessels using fuzzy C-mean clustering coupled with integrated level sets. In their study, the image was contrast enhanced by CLAHE (Contrast Limited Adaptive Histogram Equalization), morphological operations followed by a combination of Gabor and Frangi filter used to remove noise. The Fuzzy C-mean method was then used to extract an initial blood vessels network with the segmentation further refined using an integrated level set approach [20]. In another study performed by Xiao-Xia et al. an automatic technique of blood vessels extraction using curvature evaluation and entropy filtering for calculating the segmentation in relation to central light reflex vessels was recommended [21]. Wendeson et al. combined 3 filters (matched filter, Frangi's filter and Gabor wavelet filter) using two approaches of weighted mean and median ranking to improve the segmentation results obtained after application of Fuzzy C mean technique [22].

Morphological operations method deal with the application of some structuring elements to binary or gray scale images [23]. For instance, the morphological angular scale-space presented by A. Kundu, rotated a multi-scale linear structuring element at different angles for detecting connected retinal blood vessels and ensuring that the connectivity across the vessels is not lost [24].

All these reported studies revealed the different algorithms deployed in retinal blood vessels segmentation; however, there are limitations such as less connectivity, poor visibility of retinal blood vessels pattern and time consuming task that need improvement.

In this study, we introduced a mathematical morphology operations method couples with Kirsch's template based method to extract Retinal blood vessels.

The remaining part of this article is compiled in the following order; section 3.1: introduces the retinal image database, section 3.2: explains the pre-processing operations, section 3.3: describes the feature extraction operations based on mathematical morphology operations, partial contrast stretching, and Kirsch's template method, section 3.4: details the post–processing phase. The results and discussion are presented in section 4, with the conclusion in section 5

3. Materials and Method

In this work, an automatic blood vessels segmentation approach is carried out on color retinal fundus images. The pre-processing step consists of the following steps: 1) gray scale image conversion, 2) Removing the vessels central light reflex, 3) Enhancing the retinal blood vessels using CLAHE (Contrast Limited Adaptive Histogram Equalization), This is followed by feature extraction using mathematical morphology operations and Kirsch's template and lastly 2D median filter is used for post-processing step to remove noise and isolated pixels. Figure 1 shows the block diagram of our proposed segmentation framework.

3.1. Materials

In this paper, we used a publicly available online database DRIVE (Digital Retinal Image for Vessels Extraction) containing 40 color fundus digital images divided into 2 main sets: training set and test set, each containing 20 digital images. The images were captured with a canon CR5 non mydriatic 3CCD digital retinal fundus camera at 450 field of view (FOV).

The dimensions of the images are 768 × 584 pixels with 24 bits (8 bits per each color channel) [17]. All images in this database have corresponding manually segmented versions as ground truths. The Test set is used to perform and evaluate our proposed algorithm.

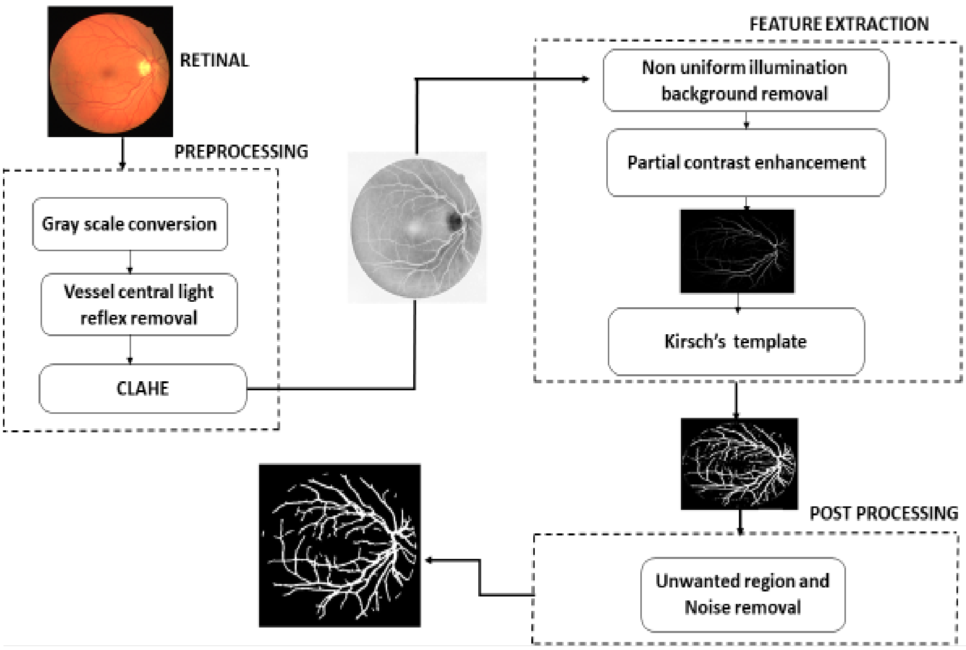

Fig. 1. Flow chart of the proposed approach.

3.2. Pre-processing

The preprocessing step is necessary, and is performed before extracting pixels' features to reduce and eliminate the imperfection poor contrast and noises presented in the color fundus image.

3.2.1. Gray Level Conversion

Conversion of gray level can be done in different ways with the aim of obtaining an intensity image. Many methods prefer to use only one of the color channels such as green channel, whereas others use the sum of the color channels with the sum of specific coefficients equal to one. The general formula is given by Craig's formula in Equation 1.

$$I = c_r * R + c_g * G + c_b * B \quad (1)$$

Where I is the intensity value; R, G and B are intensities of red, green and blue channels of a given fundus image, respectively; and c_x is the color channel coefficient.

In this paper, we choose to use the color channel coefficient $c_r = 0.3$, $c_g = 0.59$ and$c_b = 0.11$. The green channel which has the maximum contrast in between blood vessels showed the highest contrast between blood

vessels and background than red and blue

3.2.2. Vessel Central Light Reflex Removal

The retinal blood vessels have lower reflectance and appear darker than other retinal surfaces elements because their inner pixels are darker than the outermost vessels pixel.

A light streak known as vessel central light reflex that can be observed on the center of some retinal blood vessels runs down the central length of the retinal blood vessels. To remove this incidence, we carried out the opening operation with disk shaped structuring element of radius 3 ($\omega_{s_{d3}}$) on the intensity image as shown on Figure 2(b).

3.2.3. Image Contrast Enhancement

The contrast enhancement technique is an important asset in retinal image enhancement for improving and differentiate the good quality image from a low quality image. Image enhancement techniques can be classified into several different classes such as histogram, transformation, masking and filter based techniques [25]. In this paper, the histogram based technique CLAHE (Contrast Limited Adaptive Histogram Equalization) is proposed and used [26] as shown on Figure 2(c).

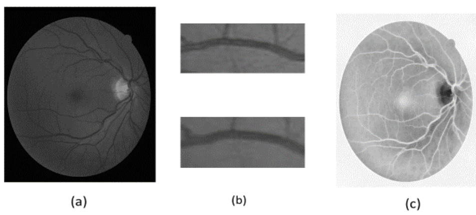

Fig. 2. Pre-processing stage: (a) gray scale image (b) upper part is from gray scale image containing the central light reflex, and lower part, after removal of the central light reflex, (c) enhanced image by CLAHE (Contrast Limited Adaptive Histogram Equalization).

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3.3. Feature Extraction

Feature extraction is carried out using different techniques of mathematical morphological operations, partial contrast stretching and Kirsch's template for retinal blood vessels network extraction.

3.3.1. Mathematical Morphological Operations

Morphological operations are mainly applied to an input image for extracting image components that are useful in image representation and removing the imperfection structure in the image.

They use the combination of 2 processes: dilation and erosion which act on the image pixels by using a small matrix known as structuring element that has the significant impact on the image result. Mathematical morphological operations formula used in this work are described below:

Let s_e be the structuring element to be operated on image I_m.
Erosion: $\in_{s_e} (I_m)$

Image I_m eroded by s_e is the set of all points p such that s_e translated by p, is contained in I_m.

Dilation: $\delta_{s_e}(I_m)$ Image I_m dilated by s_e is the set of all displacement point p such that s_e and I_m overlap by at least one element.

Compound operations

$$\text{-Opening:} \omega_{s_e}(I_m) = \delta_{s_e}(\in_{s_e} (I_m)) \quad (2)$$
$$\text{-Closing:} \tau_{s_e}(I_m) = \in_{s_e} \left(\delta_s(I_m)\right) \quad (3)$$

Since the non-uniform illumination background is presented in the retinal blood vessels after image enhancement and lead to the diminished structure and inhomogeneous intensity of the resultant image; in this study we have adopted the method used by P. Singh and K. Garg which involves estimating the background image for removing the non-uniform illumination background [27]. The enhanced image shown on Figure 2(c) is opened by a disk shaped structuring element of radius 8 ($\omega_{s_{d8}}$) Equation (4) and thereafter the processed image is subtracted from the enhanced image for removing the non-uniform illumination background, Equation (5), the obtained image is shown on Figure 3.

$$I_b = \omega_{s_{d8}}(I_{CLAHE}) = \delta_{s_{d8}}(\in_{s_{d8}} (I_{CLAHE})) \quad (4)$$
$$I_t = I_{CLAHE} - I_b \quad (5)$$

I_b is the non-uniform background extracted image, $\omega_{s_{d8}}$ is opening operation with disk shaped structuring element of radius 8, I_{CLAHE} is enhanced image by Contrast Limited Adaptive Histogram Equalization and I_t is the image obtained with the uniform background.

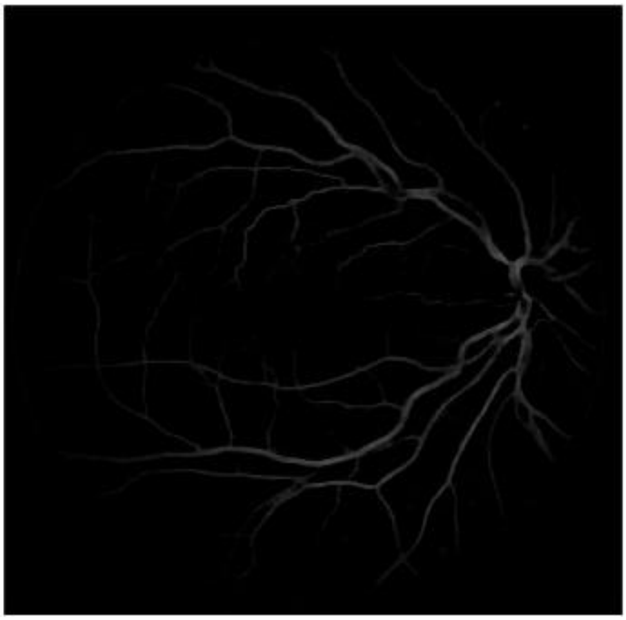

Fig. 3. Retinal blood vessel with uniform background.

3.3.2. Partial Contrast Stretching

Partial contrast stretching enhancement technique is a linear mapping function used to improve the contrast level and increase the brightness level of the image by mapping the pixel range of lower and upper threshold value to the new pixel range and stretched linearly to a wide range of pixel values. [28]. Equation 6 summarized the operation

$$I_k = (I_t - f_{min})\left(\frac{max - min}{f_{max} - f_{min}}\right) + min \quad (6)$$

Where, I_k =Partial contrast stretched image;

I_t=input image

f_{max}&f_{min}: the highest and lowest pixel values present in the input image max & min:

Upper and lower pixel value limits that determine the pixel value of partial contrast stretched image. Since the obtained image I_k presented the weaknesses of blurred, to increase the contrast and brightness level.

In this work, we took on the technique used by S. S. Al-amri, et al. [29], where the minimum value pixel which is 1 in our case is mapped to 0 and the maximum value pixel 95 stretched to 255. The resultant image is shown on Figure 4.

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Fig.4. Partial contrast stretched enhanced image.

3.3.3. Kirsch's Template Method

Kirsch's template is one of the discrete version of first order derivative used for retinal blood vessels edge enhancement and detection. Edge information of a particular target pixel is checked by determining the brightness level of the neighboring pixels. Figure 5 shows the kirsch's template uses 8 templates and rotates automatically by 45^0 increments through 8 directions South, East, North, West, Northeast, Southeast, Southwest, and Northwest

$$h_1 = \begin{bmatrix} 5 & -3 & -3 \\ 5 & 0 & -3 \\ 5 & -3 & -3 \end{bmatrix} \quad h_2 = \begin{bmatrix} -3 & -3 & 5 \\ -3 & 0 & 5 \\ -3 & -3 & 5 \end{bmatrix}$$

0^0 45^0

$$h_{3=} \begin{bmatrix} -3 & -3 & -3 \\ 5 & 0 & -3 \\ 5 & 5 & -3 \end{bmatrix} \quad h_4 = \begin{bmatrix} -3 & 5 & 5 \\ -3 & 0 & 5 \\ -3 & -3 & -3 \end{bmatrix}$$

90^0 135^0

$$h_{5=} \begin{bmatrix} -3 & -3 & -3 \\ -3 & 0 & -3 \\ 5 & 5 & 5 \end{bmatrix} \quad h_6 = \begin{bmatrix} 5 & 5 & 5 \\ -3 & 0 & -3 \\ -3 & -3 & -3 \end{bmatrix}$$

180^0 225^0

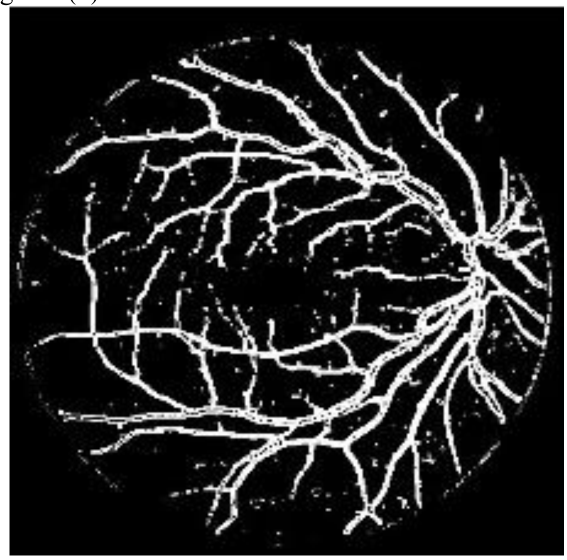
$$h_{7=} \begin{bmatrix} -3 & -3 & -3 \\ -3 & 0 & 5 \\ -3 & 5 & 5 \end{bmatrix} \quad h_8 = \begin{bmatrix} 5 & 5 & -3 \\ 5 & 0 & -3 \\ -3 & -3 & -3 \end{bmatrix}$$

270^0 315^0

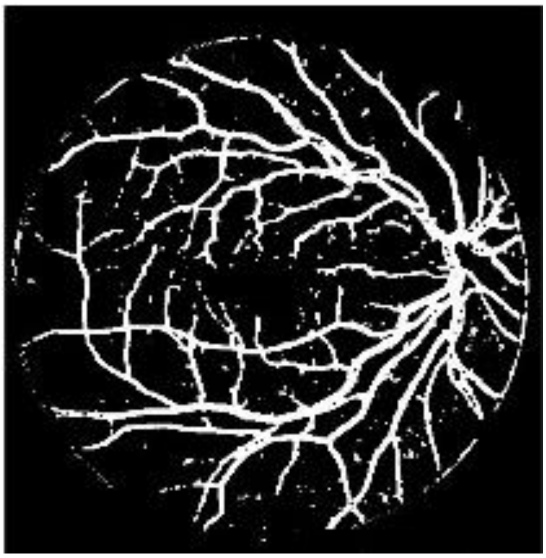
Fig. 5. Kirsch's convolution kernels.

In this study the gradient of different directions is computed and achieved by convolving the partial contrast stretched enhanced image with 8 templates impulses responses array in each and every pixel. The final gradient is obtained as shown on Figure 6(a) by setting the threshold value at 10 and summing up all the enhanced edge considered in all directions.

However the kirsch's templates have the drawback of creating small holes within the blood vessels and the unwanted small objects going through the detected blood vessels as shown on Figure 6(a). To minimize this tradeoff and eliminate the unwanted species, the morphological closing operation, Equation 3, with disk shaped structuring element of radius 1 ($\tau_{s_{d1}}$) is applied for closing the small holes in the image and preventing the shapes and size of the object image as shown on Figure 6(b).



6 (a)



6 (b)

Fig.6. (a) Extracted blood vessels image before morphological closing operation. (b) Extracted blood vessels image after morphological closing operation.

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3.4. Post Processing

Once we get the binary map of retinal blood vessels, some operations must be performed to remove the noises in the image in order to enhance the segmentation performance. We used 2D median filter for vessels line connectivity restoration by revealing some hidden pixels that belonged to the vessel line, remove the noisy pixel and the unwanted regions in the image. The final binary vessels map is presented on Figure 7 and Figure 8 shows the iterative images results of the proposed method.

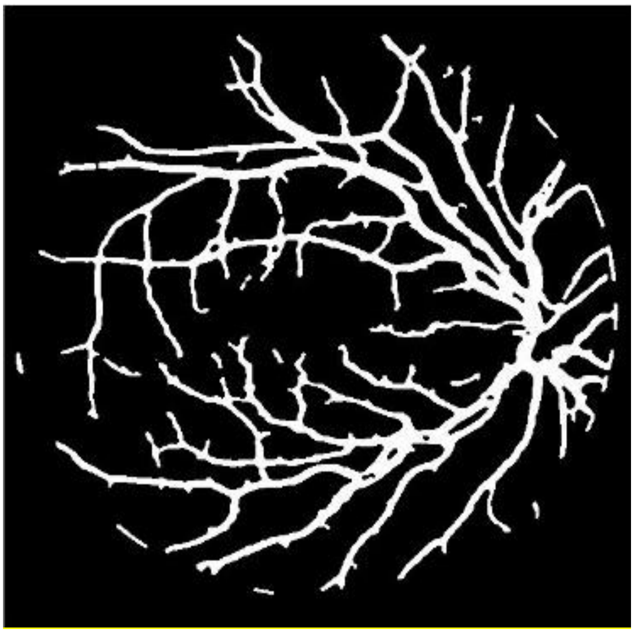

Fig. 7. Retinal blood vessels segmented image by the proposed method

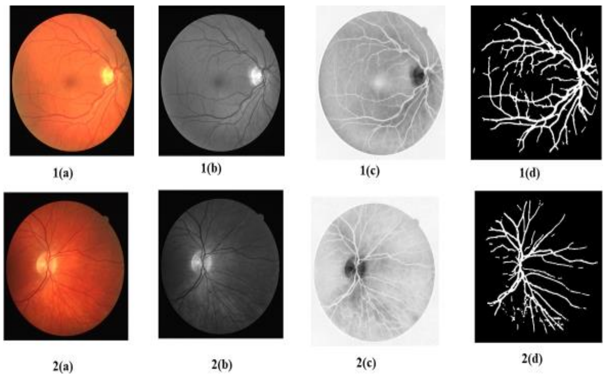

Fig. 8.Iterative images results: Figure 1 and 2 are DRIVE images 3 and 15 respectively. 1(a) and 2(a) are retinal color fundus images, 1(b) and 2(b) are grayscale images, 1(c) and 2(c) are enhanced images by CLAHE, 1(d) and 2(d) are results from the proposed segmentation algorithm.

4. Experiments Results and Discussion

We implemented our proposed Algorithm using MATLAB R2016a and testing the efficacy of the proposed method on publicly available online database DRIVE as described in section 3.1. DRIVE dataset contains 40 color fundus digital images divided into 2 main sets: training and test set both of each containing 20 digital images [17] we tested our method on all 20 test set digital images with respect to the 1st manually segmented images as ground truth data for comparison. To facilitate the evaluation of our algorithm and the performance comparison between our method and alternative retinal blood vessels segmentation approaches used similar DRIVE dataset, different parameters such as, True Positive (TP), True Negative (TN), False Positive (FP), False Negative (FN), Sensitivity, Specificity, Accuracy and time required to process a single image are derived to measure the performance of the segmentation. TP indicates the number of pixels correctly classified as vessel pixels, TN indicates the number of pixels correctly classified as non-vessel, FP indicates the number of pixels incorrectly classified as vessels and FN, the number of pixels incorrectly classified as non-vessel. Sensitivity indicates how the algorithm is able to detect the vessels pixels, while specificity shows the ability of the algorithm to detect non-vessels pixels and accuracy indicates the overall performance of the segmentation method.

The formula used to measure, Sensitivity, Specificity and Accuracy are given below:

$$\text{sensitivity (Se)} = \frac{\text{TP}}{\text{TP} + \text{FN}} \times 100$$

$$\text{Specificity (Sp)} = \frac{\text{TN}}{\text{TN} + \text{FP}} \times 100$$

$$\text{Accuracy (Acc)} = \frac{\text{TP}}{(\text{TP} + \text{TN} + \text{FP} + \text{FN})} \times 100$$

The results of this proposed work for 20 Test set images of DRIVE database with respect to the ground truth images are summarized in Table 1

Table 1: Performance analysis of the proposed algorithm on retinal color fundus images.

SL No	*Image name*	*Acc*	*Se*	*Sp*
1	01_test	93.70	85.21	94.53
2	02_test	94.10	87.77	94.83
3	03_test	93.99	74.11	96.19
4	04_test	95.51	75.57	97.53
5	05_test	95.20	72.46	97.56
6	06_test	94.64	59.32	98.45
7	07_test	94.98	71.98	97.21
8	08_test	95.01	68.47	97.51
9	09_test	94.75	73.95	96.58
10	10_test	95.28	74.90	97.10
11	11_test	94.39	74.42	96.35
12	12_test	95.05	66.43	97.76
13	13_test	94.48	75.70	96.52
14	14_test	93.79	84.33	94.62
15	15_test	94.96	79.23	96.18
16	16_test	93.99	77.90	95.59
17	17_test	94.18	72.71	96.16

18	18_test	94.45	66.93	96.82
19	19_test	94.52	80.63	95.78
20	20_test	94.99	76.17	96.48
AVERAGE		94.60	74.91	96.49

In this article we aimed at obtaining accurate retinal blood vessels network from the retinal color fundus image, at first the color fundus image is converted into grayscale image as indicated on Equation 1. We set the color coefficients at 0.3; 0.59; 0.11 for red, green and blue channel respectively.

The green channel has higher channel coefficient value for it provides better vessels background contrast than red and blue. Since the inner vessels pixels of the retinal blood vessels appear dark than the outer pixels, the bright strips located in the center of the retinal blood vessels were removed by the morphological operation with a disk shaped structuring element of radius 3 ($\omega_{s_{d3}}$) and the image was enhanced by using CLAHE (Contrast Limited Adaptive Histogram Equalization) for it produces more contrast in green channel than in red channel and blue channel by differentiating the maximum and minimum image pixel values [26].

Afterwards, the morphological operation with disk shaped structuring element of radius 8 ($\omega_{s_{d8}}$) is applied to estimate the accurate background approximation as a surface for extracting the non-uniform background according to Equation (4).

The structuring element of radius 8 is chosen as the maximum value for Erosion to avoid the image quality to be affected during erosion process, then the processed image is subtracted from the enhanced image as given by Equation (5). The results reveal various particles present in the image with exact boundaries along with the removal of the non-uniform illumination background. However, the obtained image has low contrast as shown on Figure 3.

To improve the image brightness, we carried out the Partial Contrast Stretching technique as shown on Figure 4. Afterwards, Kirsch's template is used to generate the blood vessels network. By setting different thresholds value for Kirsch's template, It is shown that when the threshold value is greater or lesser than 10, it gave the negative impact on the results. Therefore, we used the threshold value of 10 for obtaining a good performance result as shown on Figure 6 (a).

After vessel network extraction, the presented image still had some unwanted regions such as the small holes that appear in the retinal blood vessels, These were closed by applying a closing morphological operation with a disk shaped structuring element of radius 1($\tau_{s_{d1}}$) Equation (3), Figure 6(b) indicates the result obtained. The structuring element of radius 1 is chosen as the minimum value for dilation to avoid the image quality to be affected during dilation process.

Lastly, the noises present in the image were removed using 2D median filter, the result shown on Figure 7.

For our proposed approach validation, we compared our segmentation results with other published state of the art methods used similar dataset DRIVE in terms of Accuracy, Sensitivity, and Specificity as tabulated in Table 2. [12, 16, 30, 31, 32, 33, 34], and computation time required to process a single image segmentation as tabulated in Table 3. [20, 30, 31 ,34, 35, 36, 37]. The proposed method is significantly less time consuming than other approaches tested on similar dataset

Table 2: Comparison between the existing blood vessel segmentation algorithms and the proposed technique based on DRIVE database.

Author's names	***Acc (%)***	***Se (%)***	***Sp (%)***
Nagendra et al. [12]	97.21	67.35	94.59
Xu and Luo [16]	93.2	77	-
Dai et al. [30]	94.18	73.59	97.20
Marios et al. [31]	92.9	74.7	95.5
Azani at al. [32]	92.64	60.45	95.73
Farnaz and Hasan [33]	93.66	97.56	95.12
Mendoca et al. [34]	94.73	77	27.5
Proposed Method	94.60	74.91	96.49

"—" indicates that there is no available data.

Table 3: Comparative analysis of the methods in terms of time required to process a single image from the DRIVE.

Author's names	***Processing time per image (sec)***	***Software Used***
Nogol et Al. [20]	30	MATLAB
Dai et al. [30]	106	MATLAB
Marios et al. [31]	9.3	MATLAB
Mendoca et al. [34]	150	MATLAB
George et al. [35]	10	MATLAB
Peter et al. [36]	22.45	MATLAB+C^{++}
Aboul et al. [37]	165	MATLAB
Proposed Method	5	MATLAB

5. Conclusion

Retinal image is being used by ophthalmologists to aid in screening, diagnosis and identification of ophthalmologic disorders. Most times, extraction of retinal blood vessel network is a key challenge for proper analysis, visualization and quantitative comparison. The present study developed an automated method for extraction of retinal blood vessels from retinal fundus image within a short time using morphological operations method coupled with Kirsch's template. The proposed framework was validated on the publicly available retinal image dataset DRIVE.The results obtained were compared with some other existing standard methods tested and evaluated on the same DRIVE dataset. Based on the achieved results, the proposed methods is promising comparing to other existing standard methods used similar dataset in term of accuracy, sensitivity, specificity and time taken to process a single image. This showed that it is possible to extract retinal blood vessels with high accuracy within a short time.

Future work

We hope to implement and analyse the presented method in other different fields

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