Retinal Blood Vessel Extraction Method Based on Basic Filtering Schemes

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***Abstract*—The eye disease such as Diabetic Retinopathy(DR) can be analysed through segmentation of retinal blood vessels. In the last five years, many methods for retinal blood vessels segmentation were proposed. These methods give arise to the improved accuracy, however the sensitivity of low contrast vessels is often ignored. The performance of diagnosis in terms of segmentation of vessels can be degraded due to missing tiny vessels. In this study, we propose a novel algorithm aiming at improving the performance of segmenting small vessels. The proposed approach adopts a morphological and filtering method to handle the background noise and uneven illumination and uses anisotropic diffusion filtering to coherent the vessels and give initial detection of vessels, followed by a double threshold based region growing method.**

***Index Terms*—Retinal vessels, Enhancement, Adpative filtering, Binarization, Coherence**

I. Introduction

Diabetic Retinopathy (DR) is one of significant eye diseases [1], [2]. It is crticial to detect early for proper treatment because DR progressively leads to blindness [3]–[5]. The automatic detection by using image processing technologies is favourable but one must improve the accuracy and efficiency of DR detection. The automated segmentation of retinal blood vessels plays an important role in automatic analysis of retinal vessels. Most successful vessel segmentation methods are based on Morphological image processing, where vessels are assumed to be tubular structures having concave cross-section [1], [6]. Although these techniques have provided a vessel tree structure, some of low-contrast small vessels were not considered during the processing stage.

In this paper, we propose a computerised technique for segmentation of retinal blood vessels. At the first stage, the given retinal images are converted into gray RGB channels; At the second stage, which is the most crucial, contains background homogenization, noise level reduction and vessel enhancement are conducted. And the last stage includes coherence of retinal vessel network and image binarisation. In such a way, accurate vessels are effectively extracted from a given image.

The paper is organized as follows. The first section introduces the proposed method of vessels extraction. The second section includes the parameters evaluation. The third section presents the experimental results and analysis. The last section includes conclusion and discussion.

II. The Proposed Method

Our proposed method consists of three stages as shown in Fig. 1, of which each stage will be explained as follows.

A. Pre-processing of Retinal Images

First we convert the colour retinal RGB image into gray RGB channels as shown in Fig 2. The retinal vessel image often shows significant lighting variations, poor contrast and noise. In RGB retinal images, the green channel often shows the best vessel-background contrast, while the red and blue channels show low contrast and are noisy. Only does the green channel have considerable contrast as well as least noise. Thus we select the green channel for further processing in order to segment retinal vessels.

B. Background Homogenisation

One of the main problems in analysing the retinal images is uneven illumination that occurs due to image acquisition process through fundus camera. It is essential for proper segmentation of retinal blood vessels to uniform the contrast of retinal blood vessels against their background. We apply a morphological filter based on bottom hat filter with line structure of 12. The sample output of the proposed step is shown in Fig 3(a). However there exists noise that produces irregularity in the intensity of uniform background image, as evidenced by the histogram of uniform background image in Fig 3(b).

C. Noise Reduction: Adaptive Wiener Filtering

To overcome the issue of noise, the adaptive wiener filter is adopted. An adaptive filtering is a type of filtering that contains a linear filters, controlled by a variable parameter such as the standard deviation of the image. The optimal adjusted parameters give the proper noise control on the image. We adopt wiener filtering in this research work to reduce the noise in retinal images. The adaptive filters can remove image noises through modifying the values of each pixel in the image. The minimum mean square error filter (MMSEF)

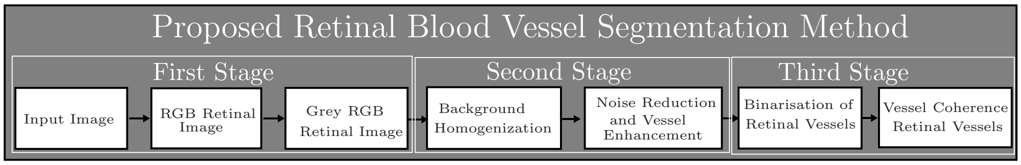
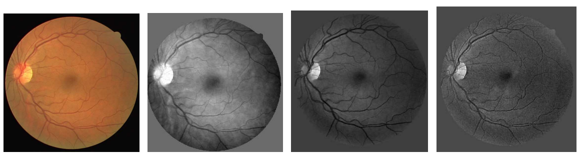


Fig. 1. Proposed Retinal Vessel Segmentation Model



(a) (b) (c) (d)

Fig. 2. Grey Scale RGB Retinal images: (a) Retinal Input Image; (b) Red Channel Image; (c) Green Channel Image; and (d) Blue Channel Image

is known as an example of such a Wiener filter. MMSEF customises itself according to local variance of the image. Where the variance is large, adaptive Wiener filter performs less smoothing. Where the variance is small, adaptive Wiener filter performs more smoothing. A linear filter of comparably same kind is less selective than an adaptive filter due to the fact that it cannot preserve the edges along with other high-frequency areas of the image [7]. The adaptive Wiener filter uses a pixel-wise adaptive technique. This method takes into account the statistical information of each pixel's local neighborhood. There are three steps for the operation of the adaptive Wiener filter. They are discussed as follows.

1) The Mean μ of noise contained image is calculated accordingly with a given mask. Equation 1 below shows the mathematical definition of the mean

$$\mu = \frac{1}{NM} \sum_{n_1=1}^{N} \sum_{n_2=1}^{M} I\left(n_1, n_2\right), \tag{1}$$

where I is the given image, (n_1, n_2) is the pixel index, and N-by-M is its local neighborhood window.

2) The Variance σ of the noisy image is calculated accordingly with a given mask too, as defined by

$$\sigma^2 = \frac{1}{NM}\left(\sum_{n_1=1}^{N} \sum_{n_2=1}^{M} I\left(n_1, n_2\right) - \mu\right)^2.. \tag{2}$$

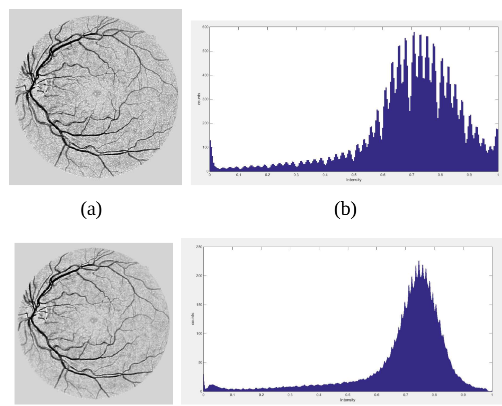
The N-by-M local neighborhood of each pixel in the image is considered same as step 1.

3) Utilising these estimates, a pixel-wise adaptive Wiener filter is conducted on the image as follows

$$F\left(n_1, n_2\right) = \mu + \frac{\sigma^2 + v}{\sigma^2}\left(I(n_1, n_2) - \mu\right), \tag{3}$$

where the noise variance is v.

In step 3, however, when no noise variance is given, the adaptive Wiener filter takes an average of all the estimated local variances for use. The sample output image from the adaptive Wiener Filtering is shown in Fig 3(c), where the low contrast tiny vessels can be clearly observed by reducing the noise level with the application of the adaptive wiener filter. Thus the intensity level should give better contrast. Histogram of wiener filtered image, shown in 3(d), gives better contrast at different levels of intensity, which evidences the better contrast for wiener images.



(a) (b)

(c) (d)

Fig. 3. (a) Morphological tactics Output; (b) Histogram of Morphological tactics Output; (c) Wiener Filter Output; and (d) Histogram of Wiener Filter Output

D. Vessels Detection

Vessels Coherence Importance: The primary goal of analysing the retinal image is to segment the blood vessel as much accurate as possible [8]–[10]. But many researchers did not consider the coherence at all in doing the segmentation of the retinal vessels [11]. We have noticed that the coherence of small retinal vessels increases the performance of segmentation method. In this paper, we take the coherence into our main consideration.

First we apply the second order Laplacian of Gaussian to detect the vessels. Although the large width vessels can be detected properly as shown in Fig 4(a), it causes discontinuity as small vessels are not detectable. Thus the binarisation stage would be affected, as it's histogram shown in Fig. 4(b) evidences that intensity at some levels are not well distributed.

To get more accurate segmentation, we apply an oriented diffusion filtering as suggested by [12] for detecting the

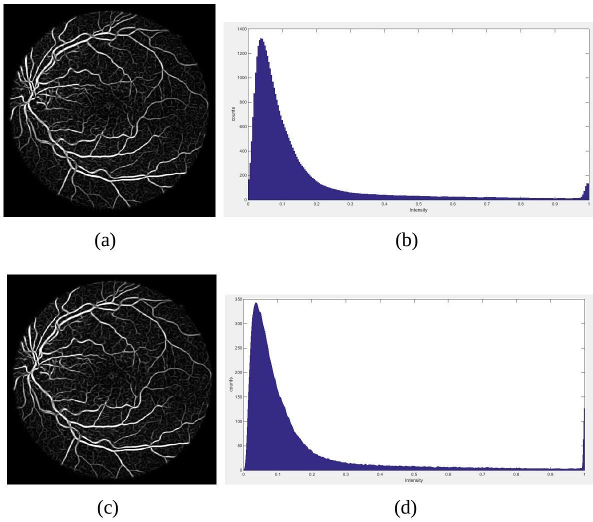


Fig. 4. (a) Second order Laplacian of Gaussian; (b) Histogram of the second order Laplacian of Gaussian; (c) Anisotropic Oriented Diffusion Filter Image; and (d) Histogram of Anisotropic Oriented Diffusion Filter Image.

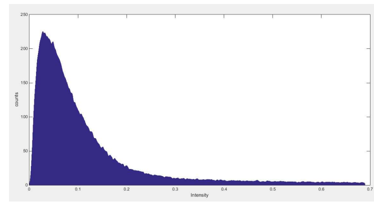


Fig. 5. Histogram with the estimated noise distribution

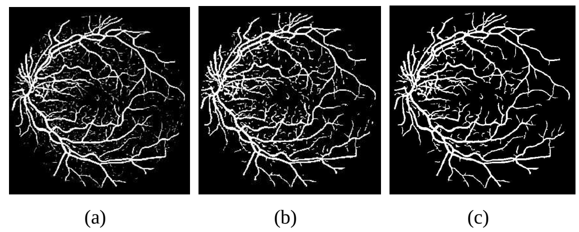


Fig. 6. (a) Image achieved at Step 2; (b) Image achieved at Step 4; and (c) Final Vessels Segment Image

low-quality fingerprints. The oriented diffusion needs pre-computed orientation data of an image in advance. Such orientation data is called as orientation field (OF). OF makes the diffusion tensor which steers according to the vessel flow direction. The motivation to use such an anisotropic diffusion process is the tilt angle data of the best ellipse. This can be done based on the second order Gaussian detector, thus it makes proper detection of tiny vessels. The diffusion process is defined as follows.

1) Compute the second-moment matrix for each pixel.
2) Make the diffusion matrix for each pixel.
3) Compute the change in intensity for each pixel as $\nabla (D \nabla I)$, where D is 2×2 diffusion matrix and I is the image input to the process.
4) Update the image using the diffusion equation as:

$$I^{t+\triangle t} = I^t + \triangle t \times \nabla (D \nabla I) . \tag{4}$$

Since the diffusion process is an iterative algorithm that evolves from the initial retinal image and will move on making structures smoother at each step [13]. There should be an appropriate stopping criterion. One such stopping criterion was introduced recently in a research work [14], [15]. The stopping iteration is based on the rate of change of *spatial entropy* value of the retinal image with respect to the iteration number. One sample output of anisotropic oriented diffusion filter is shown in Fig. 4(c) and the second order Gaussian filter in Fig. 4(a) along with their histograms in Fig. 4(b) and Fig. 4(d). It can be clearly observed that anisotropic oriented diffusion filter gives more coherence of vessels against the background as compared to the second order Gaussian filter.

Binarisation: The final vessels segment image is achieved by applying double threshold region growing method. The algorithm is described as follows,

1) Select two thresholds T_1 and T_2 automatically from the histogram of the image Fig 5. T_1 is the median value of histogram, where as the T_2 is obtained by choosing T_1 as multiple of 0.5 standard deviations subtracted from the median value of the histogram.
2) Partition the retinal image into three type regions : $A1$ containing all pixels with gray values below T_1; $A2$ containing all pixels with gray values between T_1 and T_2; and $A3$ containing all pixels with gray values above T_2. Thus $A1$ corresponds to pure background, retinal blood non-vessel region, $A2$ retinal blood vessels with gray-level intensities, and $A3$ retinal blood vessels with white intensities.
3) Visit each pixel in region $A2$. If the pixel has a neighbour in region $A1$, then reassign the pixel to region $A1$. We assume eight-connectedness, that is, a neighbour would be *North, North-East, East, South-East, South, South-West, West, or North-West* using cardinal directions.
4) Repeat step 3 until no pixels are reassigned.
5) Reassign any pixels left in region $A2$ to $A3$ to get final retinal blood vessels segmented image as shown in Fig. 6. Final vessels segmented image shows that proposed method is able to detect tiny vessels, thus resulting in improved performance in our proposed method (as shown in Fig. 6(c).

E. Material

We use the two publicly available databases (http://biomisa.org/downloads/)Digital Retinal Images for Vessel Extraction (DRIVE) and Structured Analysis of the Retina (STARE) to assess our segmentation model and each database contains 20 images. Both databases contain two independent manually segmented images as ground truth. The

MATLAB2015a on core i7 3.4GHZ with 16GB memory is used to implement the proposed algorithm.

F. Measuring Parameters

The performance of the proposed method for segmentation of the retinal blood vessels is evaluated by the comparision against the ground truth images of the corresponding images. To measure the ability of detection of blood vessels through the proposed method, three measures are used: namely, the accuracy, the sensitivity, and the specificity. To calculate these three parameters, the four measures are required accordingly: the true positive (TP), the false positive (FP), the true negative(TN) and the false negative (FN).The accuracy is defined as the ratio of sum of the number of pixels in the correctly identified vessels and non-vessels to the sum of total number of pixels, Accuracy $= \frac{TP+TN}{TP+FP+FN+TN}$. The sensitivity is defined as the ratio of the number of pixels in correctly identified vessels to the total number of vessels Sensitivity $= \frac{TP}{TP+FN}$. And the specificity is used as the ratio of the number of pixels in correctly detected nonvessels to the total number of non-vessels Specificity $= \frac{TN}{TN+FP}$.

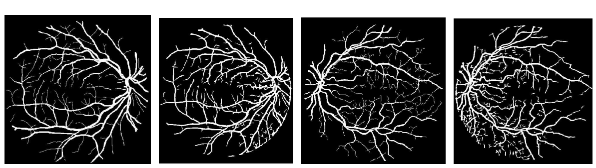
III. Experimental Results and Analysis

The performance of our proposed method is elaborated in Table I which tabulates the accuracy, sensitivity, and specificity value of DRIVE and STARE database.

TABLE I
ANALYSIS OF RESULT OF DRIVE AND STARE DATABASE

Database	Accuracy	Sensitivity	Specificity
DRIVE	**95.15%**	**74.65%**	**96.46%**
STARE	**95.05%**	**74.98%**	**95.96%**

After analysing the results in the above statistical outcomes in the Table, we conclude that our proposed method is capable of providing the accuracy up to 94%. We have compared the output images with the ground truth images as shown in Fig 7 which shows 2 sample images of both right and left eyes.



(a) (b) (c) (d)

Fig. 7. Analysis of ouput images: (a) Ground truth (Right Eye Image); (b) Output Image (Right Eye Image); (c) Ground truth (left Eye Image); and (d) Output Image (left Eye Image)

A. Comparison with Other Methods

In addition to analysing the results from the proposed method, we also compare the performance against other existing methods of blood vessel extraction for the same datasets. Table II shows the results of other existing methods.

TABLE II
PERFORMANCE ANALYSIS OF SEGMENTATION MODEL

Image	DRIVE			$STARE$		
Methods	Se	Sp	AC	Se	Sp	AC
Steal et al [16]	-	-	0.946	-	-	**0.951**
Soares et al [17]	-	-	0.946	-	-	0.948
Lupascu et al [18]	0.720	-	**0.959**	-	-	-
You et al [19]	0.741	0.975	0.943	0.726	0.975	**0.949**
Marin et al [20]	0.706	0.980	0.945	0.694	0.981	**0.952**
Orlando et al [21]	**0.785**	0.967	-	-	-	**0.951**
Wang et al [22]	-	-	0.946	-	-	**0.952**
Mendonca et al [23]	0.734	0.976	0.945	0.699	0.973	0.944
Palomera-Perez et al [24]	0.66	0.961	0.922	**0.779**	0.940	0.924
Matinez-Perez et al [25]	0.724	0.965	0.934	0.750	0.956	0.941
Al-Diri et al [26]	0.728	0.955	-	0.752	0.968	-
Fraz et al [1]	0.715	0.976	0.943	0.731	0.968	0.944
Nguyen et al [27]	-	-	0.940	-	-	0.932
Bankhead et al [28]	0.703	0.971	0.9371	**0.758**	0.950	0.932
Our Method	**0.746**	0.966	**0.952**	**0.755**	0.959	**0.951**

Table II contrasts the performance of the proposed segmentation method against 15 other novel and state-of-the-art segmentation methods. It can be seen that the proposed method gives the highest sensitivity except for the method in Orlando et al. [21] with no accuracy on DRIVE and no performance on STARE databases given. In terms of accuracy, the propose method gives the highest accuracy, except for the method in Lupascu et al. [18], but with a lower sensitivity and no report on the performance on the STARE database.

Based on the above observation, we confidently conclude that our propose method outperforms other methods in terms of the sensitivity in detecting retinal vessels and the sensitivity is the primary parameter that gives information of tiny vessels detection.

IV. Conclusion

In this paper, we propose the segmentation method for retinal blood vessels. First, we adopt the morphological tactics to remove uneven illumination, then use the adaptive Wiener filtering to reduce levels of the uniform image. Then, we use the second order Laplacian of Gaussian along with an anisotropic diffusion filtering to make a coherent vessels network and initially analyse the vessels detection by especially concerning the tiny vessels. At the end we use the double threshold binarisation to get a well segmented image. The proposed method gives an acceptable performance (average accuracy 94%) on two publicly-accessible databases named DRIVE and STARE. Comparison experiments against other methods have demonstrated that our proposed computerised based vessel segmentation method outperforms other approaches.

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