Retinal Vessel Extraction by using Local Entropy based Thresholding and Directional Filters

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***Abstract*— Accurate extraction of retinal blood vessels is very important task in the diagnosis of various retinopathies. Directional filtering is a simple yet effective method for vessel extraction. Number of direction templates used for filtering effects the results. More the number of directional templates used, more precise the results are. In this paper, we propose a novel extension to directional filters method .The proposed method is composed of the Local entropy based thresholding method to extract thin vessels from the retinal image and the eight directional filter templates are provides filtering. The purposed method is very simple, however it significantly reduce the false detection rate and detect fine vessels that were missed by the directional filters based method.**

Keywords—Retinal images; Local Entropy based Thresholding; Directional filters; DRIVE dataset.

I. INTRODUCTION

Assessment of the characteristics of vessels plays an important role in a variety of medical diagnoses. For these tasks measurements are needed of e.g., vessel width, color, reflectivity, tortuosity, abnormal branching, and occurrence of vessels of a different width. When large number of vessels present in image, then manual delineation of the vessels becomes tedious or even Impossible. While increased size and volume in medical images required the automation of the diagnosis process, the latest advances in computer technology and reduced costs have made it possible to develop such systems. Blood vessel delineation on medical images forms an essential step in solving several practical applications such as diagnosis of the vessels (e.g. stenosis or malformations) and registration of patient images obtained at different times.Thus automated extraction of retinal blood vessels from retinal image plays an important role in the diagnosis of various retinopathies like Diabetic retinopathy[1],glaucoma[2].

In simple histogram equalization, smoothening smaller and thin vessels get averaged out as background. Then we have to apply thin vessels enhancement techniques. But the accuracy of the results would also depend on the efficiency of the vessel

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segmentation algorithm. It should be able to remove other structures like the optic disc, fovea centralis etc. and extract only the retinal vessels, as false detections affect the accuracy of the result. We know that retinal blood vessel extraction is very challenging task because of low contrast of images as shown in Fig .1(a) and 1(b).

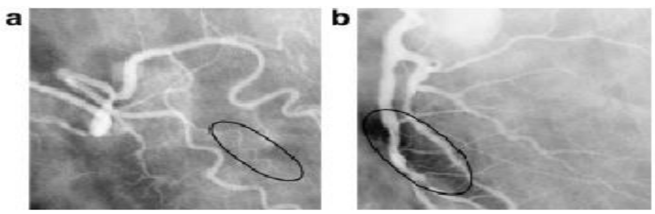

Fig. 1. *Angiography images having typical impadiment for accurate vessel-tree reconstruction such as (a) vessels with low contrast and; (b) non-uniform illumination[3].*

II. RELATED WORK

In the literatures, different approaches were used for the retinal blood vessel extraction.

A. Mathematical morphology schemes

Retinal vessel extraction can be done by morphological closed operation [4] and thresholding .In this method, the colour fundus image and the input RGB image is converted to the green channel image and the morphological close operation is used with two different structuring elements and finally the threshold is applied on the image and the output will be the binary image of the retinal vessel extracted from the back-ground.

This method was simple and efficient. Morphological connected-set filter, was utilized by Wilkinson and Westenberg [5] to capture filamentous structures. Zana and Klein [6] purposed a method in which, morphological operators such as erosion, dilation, and Top-Hat was used to enhance the shape of the artery and remove other points. In [7], three stages were employed for accurate retinal blood vessel extraction, first stage was pre-processing of retinal image to generate the green channel image and second stage was retinal image enhancement and third stage was blood vessel segmentation using morphological operations.

Zana and Klein have proposed a technique in [8], that combines morphological filters and cross-curvature evaluation, which was used in blood vessel segmentation.

B. Tracking based approaches

A new system was proposed for the automatic extraction of the vascular structure [9] in retinal fundus images, sparse tracking technique was proposed [10]. In this method, FCM classifier was used to find blood vessel points in the cross-section. The algorithm presented in [11] automatically identifies the seed point of tracing, expressed as local grey-level minima and also applied directly at the image intensity level without pre-processing. Then vessel boundaries are detected by using series of exploratory searches that helps in the estimation of next vessel point. Method used in [12] was purely graph based approach for blood vessel boundary.

C. Region growing and ridge based approaches

Soares et al. [13] have proposed an algorithm. In this method supervised classification technique is applied for the segmentation of retinal vessels. In [14], method presented was a multi-scale feature extraction and region growing algorithm for retinal blood vessels segmentation. A pixel feature based method that additionally[15] analyzed the vessels as elongated structures. Method in [16] was the system based on extraction of image ridges, which coincide approximately with vessel centerlines. Mendels et al. [17] proposed a technique based on active contour driven external forces. Martinez-Perez et al. have proposed a method for vessel enhancement. In this method two stage region growing procedure was followed [18,19].

D. Neural network based approaches

Neural networks used for blood vessel extraction, In this method, Blood vessels were identified by means of a multilayer perceptron neural networks [20][21] . Blood vessels were detected using two-dimensional matched filters [22].

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Multilayer perceptron neural network [23] was also used for retinal blood vessels detection.

E. Matching filter based approaches

In [24], frequency and orientation of Gabor filter were tuned to match that of a part of blood vessels to be enhanced in a green channel image. Segmentation of blood vessels pixels are classified by local entropy thresholding technique.

Many linear and non-linear filtering [25][26] approaches were also used in some work. Hessian-based multiscale filtering [27],used for vessel extraction. Vallabha et al. have proposed a method for automated detection and classification of vascular abnormalities in diabetic retinopathy [28] [29].

Matching filter [30] was also used for the retinal blood vessel extraction. The Matched filter uses simply filtering and thersholding to detect the retinal blood vessels from the original retinal fundus image. Advantages of this method were simplicity and effectiveness. But Matched filter have strong response to non-vessel edges also along with vessels .Possibility of false detections were more.

Use of first order derivative of this Gaussian function instead of simple Gaussian function helps to improve the [31] false positive rate. But, this method, was not able to detect thin vessels from retinal fundus image.

All the above discussed methods for vessel detection have some advantages and disadvantages, these methods were not able to accurately extract thin blood vessels .which is due to large false detection rate.

As already mentioned, method proposed in [31] was quite good in achieving large vessel extraction accuracy and smaller value of false detection rate.

We build on this work, as method in [31] uses only directional filters to take filtering operation in different orientations, we add local entropy based thresholding with this method .Local entropy based thresholding first enhance the thin retinal vessels in input retinal image and then the eight directional filter templates are applied to the resulting image to extract retinal blood vessels. Due to inclusion of local entropy based thresholding stage, thin retinal vessels are also detected, which results into an improved false detection rate.

III. THE PROPOSED RETINAL BLOOD VESSEL EXTRACTION METHOD

A. The local entropy thresholding algorithm

The entropy of a system was proposed by Shannon [32]. Shannon's function is based on the concept that information gained from an event is inversely related to its probability of occurrence. Several researchers have used this concept to image processing problems. They can partition the image into object and background. An efficient entropy-based thresholding algorithm is used to retinal blood vessel detection [33]. This algorithm takes into account the spatial distribution of gray levels, because the image pixel intensities are not independent of each other. According to this, two images with same histograms but different spatial distribution will result in different threshold values. Given image F is a P×Q dimensional matrix, $[t_{ij}]_{P\times Q}$ is the co-occurrence matrix of the image F , this co-occurrence matrix gives an idea about the transition of intensities between adjacent pixels, indicating spatial structural information of an image.

$$\text{When } \sigma=1 \text{ if } \begin{cases} f(l,k) = i \text{ and } f(l,k+1) = j \\ \quad OR \\ f(l,k) = i \text{ and } f(l+1,k) = j \end{cases}$$

$$\sigma=1 \text{ otherwise.}$$

In the algorithm, the t_{ij} is defined as $t_{ij}=\sum_{l=1}^{P}\sum_{k=1}^{Q}\delta$, so the probability of co-occurrence p_{ij} of gray level i and j can be written as

$$P_{ij}=\frac{t_{ij}}{\sum_i \sum_j t_{ij}}$$

If s is a threshold and 0<=s<=1 , then s can partition the co-occurrence matrix into 4 quadrants, such as A, B, C, and D regions. Let us define the following quantities:

$$P_A=\sum_{i=0}^{s}\sum_{j=0}^{s} p_{ij}$$

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$$P_C = \sum_{i=s+1}^{L-1} \sum_{j=s+1}^{L-1} p_{ij}$$

Normalizing the probabilities within each individual quadrant, we get the following cell probabilities for different quadrants:

$$p_{ij}^{A} = \frac{p_{ij}}{p_A} = \frac{t_{ij} / \left(\sum_{i=0}^{L-1} t_{ij}\right)}{\sum_{i=0}^{s}\sum_{j=0}^{s} t_{ij} / \sum_{i=0}^{L-1}\sum_{j=0}^{L-1} t_{ij}}$$

$$p_{ij}^{C} = \frac{p_{ij}}{p_C} = \frac{t_{ij}}{\sum_{i=s+1}^{L-1}\sum_{j=s+1}^{L-1} t_{ij}}$$

Thus, the second-order entropy of the object can be defined s,

$$H_A^{(2)}(s) = -\frac{1}{2}\sum_{i=0}^{s}\sum_{j=0}^{s} p_{ij}^{A} \log_2 p_{ij}^{A}$$

Similarly, the second-order entropy of the background can be written as

$$H_C^{(2)}(s) = -\frac{1}{2}\sum_{i=s+1}^{L-1}\sum_{j=s+1}^{L-1} p_{ij}^{C} \log_2 p_{ij}^{C}$$

Hence, the total second-order local entropy of the object and the background can be written as $H_T^{(2)}(s)$

$$H_T^{(2)}(s) = H_A^{(2)}(s) + H_C^{(2)}(s)$$

We can get the optimal threshold for object-background classification from the gray level corresponding to the maximum of $H_T^{(2)}(s)$. Then the thin vessel networks are obtained, but some of the thick vessels are still not detected. As a result, an adaptive thresholding algorithm is introduced to overcome the problem.

B. Directional filters followed by thresholding

In this paper, filter convolves the result image after local entropy thresholding with directional filter coefficients of the filter and the filtering process is denoted as

$P_i = P_o * c_j$ where (i=1,2,3,….,8; j=1,2,3,....,8),where P_I is the filtered image, P_o denotes the local entropy threshold result image and c_j denotes the directional filter coefficients. The eight directional filter coefficient templates are tabulated in Table 1.

Blood vessels can be accurately extracted using eight different templates for filtering .maximum response image can be selected by taking sum of two templates. After this maximum response image is selected by threshold value.

TABLE I. THE DIRECTIONAL FILTER COEFFICIENTS

Filter coefficient	Template value
C_1	$\begin{bmatrix}1 & 0 & 0\\0 & -1 & 0\\0 & 0 & 0\end{bmatrix}$
C_2	$\begin{bmatrix}1 & 0 & 0\\0 & -1 & 0\\0 & 1 & 0\end{bmatrix}$
C_3	$\begin{bmatrix}0 & 0 & 0\\0 & -1 & 1\\0 & 0 & 0\end{bmatrix}$
C_4	$\begin{bmatrix}0 & 0 & 0\\1 & -1 & 0\\0 & 0 & 0\end{bmatrix}$
C_5	$\begin{bmatrix}0 & 0 & 1\\0 & -1 & 0\\0 & 0 & 0\end{bmatrix}$
C_6	$\begin{bmatrix}0 & 0 & 0\\0 & -1 & 0\\0 & 0 & 1\end{bmatrix}$
C_7	$\begin{bmatrix}0 & 0 & 0\\0 & -1 & 0\\1 & 0 & 0\end{bmatrix}$
C_8	$\begin{bmatrix}1 & 0 & 0\\0 & -1 & 0\\0 & 0 & 0\end{bmatrix}$

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IV. RESULT AND DISCUSSION

The performance of purposed method is tested on publicly available dataset DRIVE [34]. This dataset also have manually segmented images. Which are taken as ground truth images in performance analysis of proposed method. The parameters

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used in Mar'ın et al. [35] are utilized to measure the performance of the proposed results and they are given in

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

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

$$\text{False Positive Rate (FPR)} = \frac{FP}{(FP+TN)}$$

Specificity is defined as the ratio between the number of TN and the sum of the total number of FP plus TN. The value of specificity also lies between 0 and 1.The parameter specificity is calculated with respect to ground truth images available in the corresponding datasets.

The value of Sp should be high for better vessel segmentation results. The true positive is the number of correctly detected blood vessels, true negative is the number of wrongly detected blood vessels, and false positive and false negative are the number of correct and wrong detected non-blood vessel pixels. False Positive Rate (FPR) is defined as the ratio between the number of FP and the sum of the total number of FP and TN. For good vessel extraction method value of FPR should be minimum. FPR is totally opposite of specificity, can also be calculated as

False Positive Rate (FPR) =1- Specificity

Performance of this algorithm is evaluated on DRIVE dataset[34] and one best and worst case is detected, according to value of the above mentioned parameters.

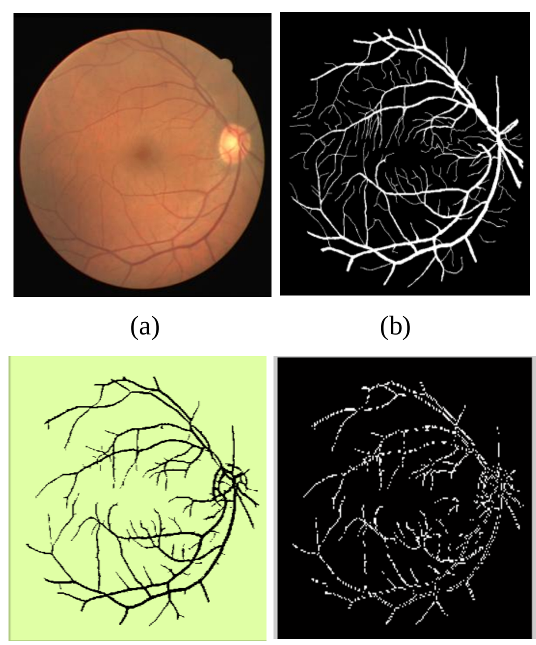
Best case in which specificity rate 98.7 and accuracy rate of 92.5 and false positive rate of 0.0128. In worst case specificity rate 96.5 and accuracy rate of 91.42 and false positive rate of 0.0345. these parameter results for best and worst case are represented in tabular form in Table 2.Input image ,ground truth image, local entropy based thresholding, method proposed is performed on DRIVE database[34].Which includes 21 test images of retina and their respective manually segmented images. Parameter results are shown for two images only, which gives best and worst possible results. Thresholding result image and final extraction result image for best and worst case are shown in Fig 2 and Fig 3 respectively. The obtained results are compared with state of art [30-31] shown in Table 3. The MATLAB R2013a version is used in this paper for the detection of blood vessels.

TABLE II. PARAMETER RESULTS OF PROPOSED METHOD FOR BEST AND WORST CASE

Parameters	***Result output of the proposed method (Best case)***	***Result output of the proposed method(Worst case)***
Specificity	98.7	96.5
Accuracy	92.5	91.4
False Positive Rate (FPR)	0.0128	0.0345

TABLE III. PARAMETER COMPARISON

Method	***Specificity***	***Accuracy***	***False Positive Rate(FPR)***
Matched filter	97.8	94.8	0.0218
MF-FDOG	97.7	95.1	0.0221
Proposed method	98.7	92.5	0.0128



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

Fig. 2. *Best case (a) input image; (b) Ground truth image(c) Local entropy thresholding.result image (d)Final extraction result image*

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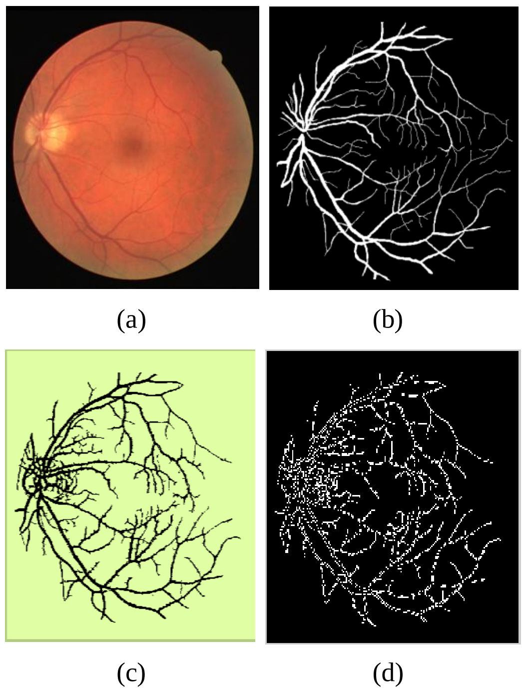

Fig. 3 *Worst case. (a)input image ; (b) Ground truth image(c)Local entropy thresholding result image(d) Final extraction result image*

V. CONCLUSION

Retinal blood vessel extraction method is proposed in this paper, local entropy based thresholding method combined with directional filtering method helps in order to detect small and thin retinal blood vessels. The performance of the proposed segmentation methodology was analyzed with respect to ground truth images in publicly available dataset DRIVE, consisting of normal and abnormal retinal images. The proposed system achieved the average vessel segmentation accuracy of 92.5% and specificity 98.7% and FPR of 0.0128, with the ground truth images of this dataset.

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