Power Law Enhancement Based Fuzzy C-Means Retinal Blood Vessel Segmentation

Sekar Mohan, Vijayarajan R

Abstract: ***The detection and analysis of retinal blood vessels is vital for the diagnosis and treatment of retinal diseases. Characteristics such as vessel lengths, diameters, bifurcations, tortuosity and reflectivity are the key to analyze retinal blood vessels for hypertension, diabetic retinopathy and macular degeneration. This manuscript proposes a power law enhanced Fuzzy C-Means method for retinal blood vessel segmentation. Morphological operations are also used to get proper vessel structure and to eliminate unwanted regions. The proposed methodology is experimented for various values of gamma and the appropriate value is suggested for power law enhancement of retinal images. For performance evaluation, normal retinal images from STARE database are tested and the results are compared with other methods experimented on the same database. It is observed from the metrics that the proposed methodology is able to achieve average accuracy of 98.45%.***

Index Terms: ***Fuzzy C-Means, Morphological operations, Power Law Enhancement, Retinal vessel segmentation, Retinopathy.***

I. INTRODUCTION

Diabetes related health issues are the major cause of concern among the elderly people all over the world. This increases year by year and hence medical experts and researchers look for feasible solutions to curtail the complications caused by the diabetes. The detection and analysis of retinal blood vessels is vital for the diagnosis of retinal diseases caused by diabetic's mellitus complications [1,2]. Characteristics such as vessel length, diameter, bifurcation, tortuosity and reflectivity are the key to analyze retinal blood vessels for hypertension, diabetic retinopathy and macular degeneration. Diabetic retinopathy can be classified into proliferative and non-proliferative [3]. In proliferative retinopathy, abnormal new vessels start to grow in the retina. Non-proliferative is the early stage of diabetic retinopathy in which accumulation of proteins and lipids causes bleeding in capillaries [4]. Early detection of this complications helps in the prevention of vision loss among the diabetic patients. Retinal blood vessel analysis also contributes to the diagnosis of glaucoma, hypertension and obesity [5].

Manual segmentation of blood vessels is a laborious task that needs a lot of skills, training and time. This can be automated in the form of computer aided diagnosis tool that can segment retinal blood vessels for further analysis of vessel diameter, thickness and so on. This manuscript analyses the performance of Fuzzy C-Means blood vessel segmentation method for power law enhanced retinal images (PLFCM). Retinal images are subjected to power law enhancement to give emphasis to the gray values of blood vessels. Once the blood vessels are segmented by Fuzzy C-Means method, morphological operations applied to eliminate small and unwanted regions in the retinal image. Metrics such as sensitivity (SE), specificity (SP) and Accuracy (AC) are evaluated with the help of ground truth images. For the experiments, normal retinal images from the STARE dataset are tested and compared with other algorithms.

II. POWER LAE ENHANCED FUZZY C-MEANS SEGMENTATION

Various enhancement techniques have been used as pre-processing step in combination with different segmentation algorithms. Vermeer et al [6] used Laplacian filter and thresholding for enhancement and blood vessel segmentation respectively. Ocbagabir et al. [4] suggested adaptive histogram equalization and morphological operations for enhancement. For blood vessel segmentation star networked pixel algorithm is suggested. This manuscript uses power law enhancement to give emphasis to the gray values of blood vessels.

A. Power Law Enhancement

This is the enhancement algorithm which gives emphasis to certain range of gray values with the appropriate selection of 'γ'. If '$I_i(x,y)$' is the input image, then the power law transformed image is given by

$$I_o(x,y) = C * [I_i(x,y)]^{\gamma} \qquad (1)$$

B. Fuzzy C-Means Clustering

FCM algorithm is a clustering algorithm used to classify blood vessel pixels from other pixels in the retinal images [7]. FCM assigns membership values which demonstrate the belongingness of all pixels to all the clusters. FCM algorithm updates the cluster centers and membership values for each pixel in the retinal images. The membership matrix U_{ij} is randomly initialized to start the iteration process. The cluster centers and membership matrix are updated based on objective function, defined by

$$J(U,C)=\sum_{i=1}^{C}\sum_{j=1}^{n} U_{ij}^{m} d_{ij}^{2} \qquad (2)$$

U_{ij} takes the values between 0 and 1. 'C' denotes the number of clusters. 'd_{ij}' denotes the Euclidian distance between cluster center of i^{th} cluster and j^{th} pixel of a retinal image. 'j' changes from 1 to n where 'n' is the number of pixels in the retinal image. 'm' is a weighting factor that takes the value between 1 and infinitive.

Revised Manuscript Received on December 22, 2018.
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The cluster center 'C_i' is updated by

$$C_i = \frac{\sum_{j=1}^{n} U_{ij}^{m} x_j}{\sum_{j=1}^{n} U_{ij}^{m}}; \quad \& \quad U_{ij} = \frac{1}{\sum_{k=1}^{C}\left(\frac{d_{ij}}{d_{kj}}\right)^{\frac{2}{(m-1)}}} \tag{3}$$

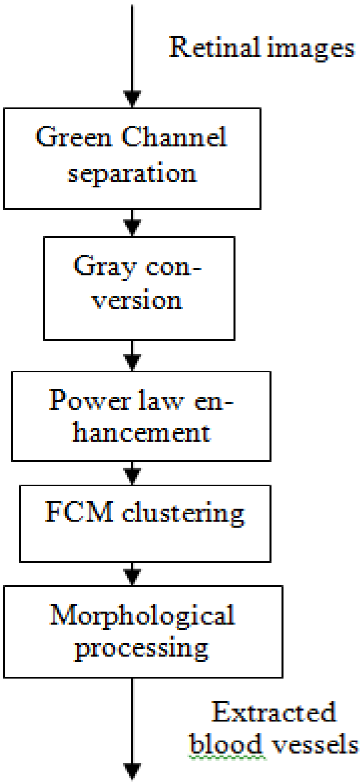

Fig. 1: PLFCM Blood Vessel Segmentation

C. Algorithm

1. Green channel is separated from the input retinal images and convert to gray image
2. Apply pre-processing filters to the converted gray channel image as stated below

(a) Gaussian filter with a standard deviation of 2.5 is applied to the images

(b) Hessian 2D filter is applied to images with a standard deviation of 2

3. FCM is applied to the filtered image as stated in section 2.2. This segmentation procedure is named as power law enhanced FCM clustering blood vessel segmentation (PLFCM)
4. Once blood vessels are extracted, adaptive histogram equalization is applied for contrast enhancement which is followed by Isodata algorithm to find a threshold value.
5. Convert the image into binary image using the threshold value that eliminates unwanted regions in the segmented retinal images.
6. Morphological operations are applied to the contrast enhanced segmented blood vessels to eliminate small and unwanted regions. Morphological operations also fill the gaps to get complete blood vessels. With morphological operations, the algorithm is named as 'PLFCMMOR'.

III. RESULTS & ANALYSIS

For experiments, retinal images with ground truth are accessed from STARE dataset. Thirty images are experimented and the subjective results are given in Fig. 3 & 4 for ten retinal images. The performance of the suggested PLFCM segmentation algorithm is analyzed by three experiments. In the first experiment, the retinal images are subjected to power law enhancement with various values of 'γ' and accuracy is evaluated. One value of 'γ' is suggested for enhancement of retinal images. Second experiment is conducted by applying FCM clustering for blood vessel segmentation. Third experiment deals with morphological operations to eliminate unwanted and small regions in the segmented image.

A. Performance Metrics

The performance of PLFCM blood vessel segmentation is evaluated by three metrics such as sensitivity (SE), specificity (SP) and accuracy (AC). These metrics are evaluated based on true positive rate (TPR), true negative rate (TNR), false positive rate (FPR) and false negative rate (FNR). TPR represents the number of correctly identified blood vessel pixels whereas TNR defines the number of correctly classified non-blood vessel pixels. FPR defines incorrect classification of non-blood vessels as blood vessels and FNP represents vice versa.

$$SE = \frac{TPR}{TPR+FNR}; \qquad SP = \frac{TNR}{TNR+FPR}; \tag{4}$$

$$AC = \frac{TPR+TNR}{TPR+FPR+TNR+FNR} \tag{5}$$

B. Power Law Enhancement Analysis

Power law enhancement is used to give more emphasis to gray values of blood vessels. Various values of 'γ' are experimented on the input retinal images and the suitable 'γ' value is suggested for enhancement by evaluating segmentation accuracy. This is given in Fig. 2 and subsequently established that the 'γ' value of 1.6 is used for all the images.

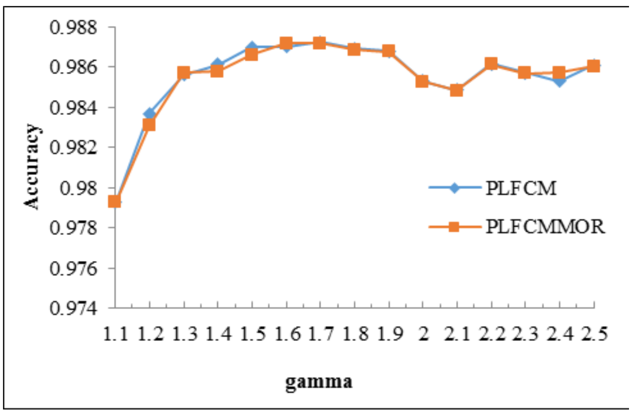

Fig. 2 Accuracy for various values of Gamma

C. Blood Vessel Segmentation Performance Analysis

Performance of blood vessel segmentation is analyzed by sensitivity, selectivity and accuracy. For analysis, metrics are evaluated before and after applying morphological operations to the segmented blood vessels.

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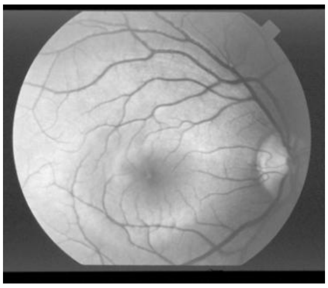
Morphological operations are used to eliminate unwanted regions or small segments separated by FCM clustering algorithm. From the metrics given in Table 1, 2 & 3, it is revealed that the morphological operations remove small segments and at the same time, terminations of the blood vessels are also getting removed. These operations make a thin blood vessel into thicker one. Because of these two reasons, blood vessels segmented after applying morphological operations lead to degradation in performance. This can be overcome by properly selecting structural elements and size of the structural elements. Table 4 gives average of all the three metrics for all the input images from the STARE dataset.



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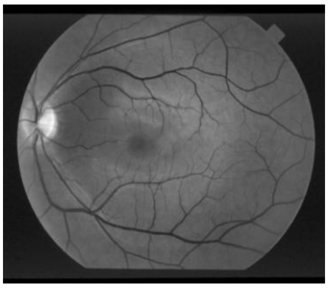
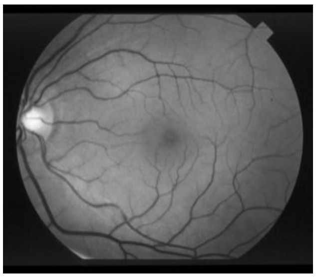
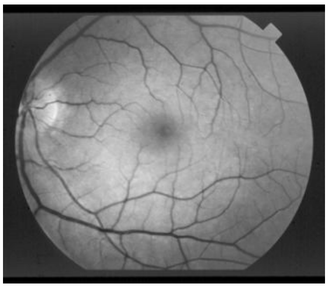


(j)

Fig. 3. (a)-(j) Normal retinal images from STARE dataset



(a)



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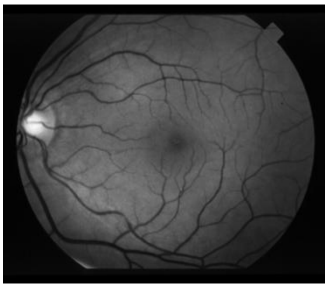
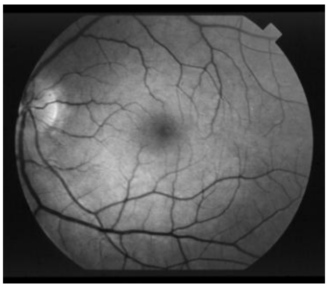


(a)



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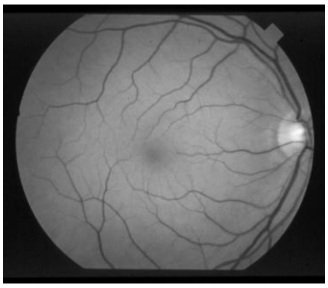

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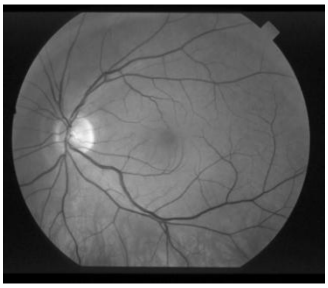

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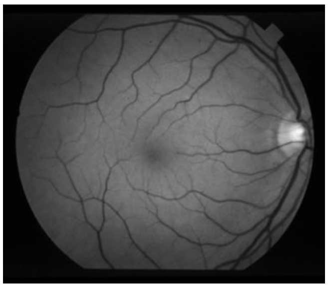

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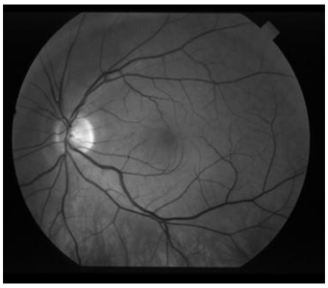

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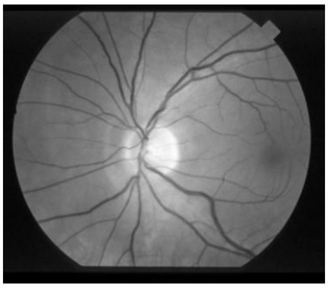

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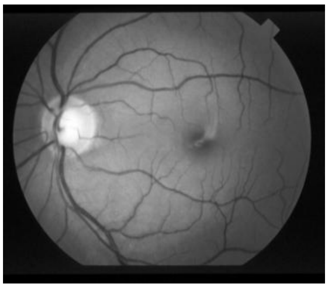

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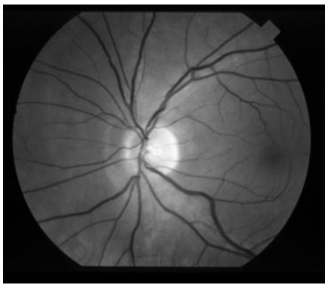

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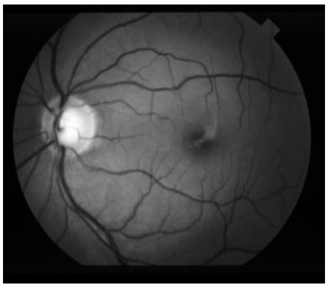

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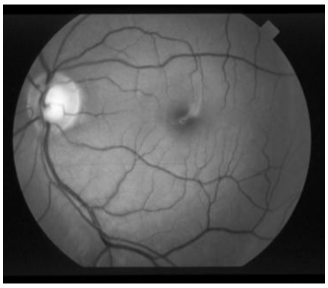

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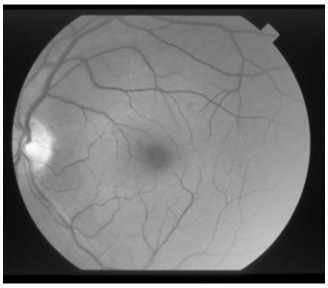

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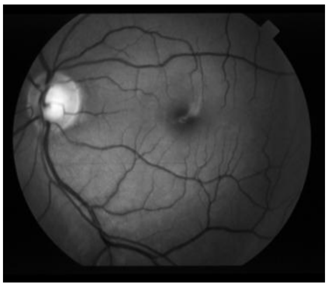

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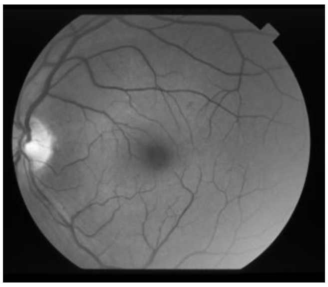

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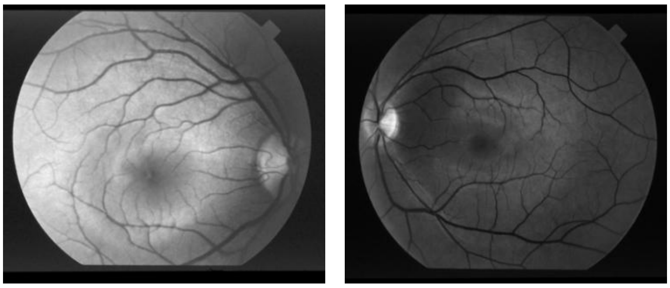


(i) (j)

Fig.4. Power law enhanced Green channel images (γ=1.6)

Table 1: Performance metric (Sensitivity)

	Sensitivity	
	PLFCM	**PLFCMMOR**
Image1	0.829933	0.819093
Image2	0.887756	0.876024
Image3	0.825339	0.817158
Image4	0.794865	0.784481
Image5	0.738693	0.717593
Image6	0.81639	0.810063
Image7	0.890011	0.881657
Image8	0.712608	0.689495
Image9	0.809737	0.797698
Image10	0.848326	0.848326

Table 2: Performance metric (Specificity)

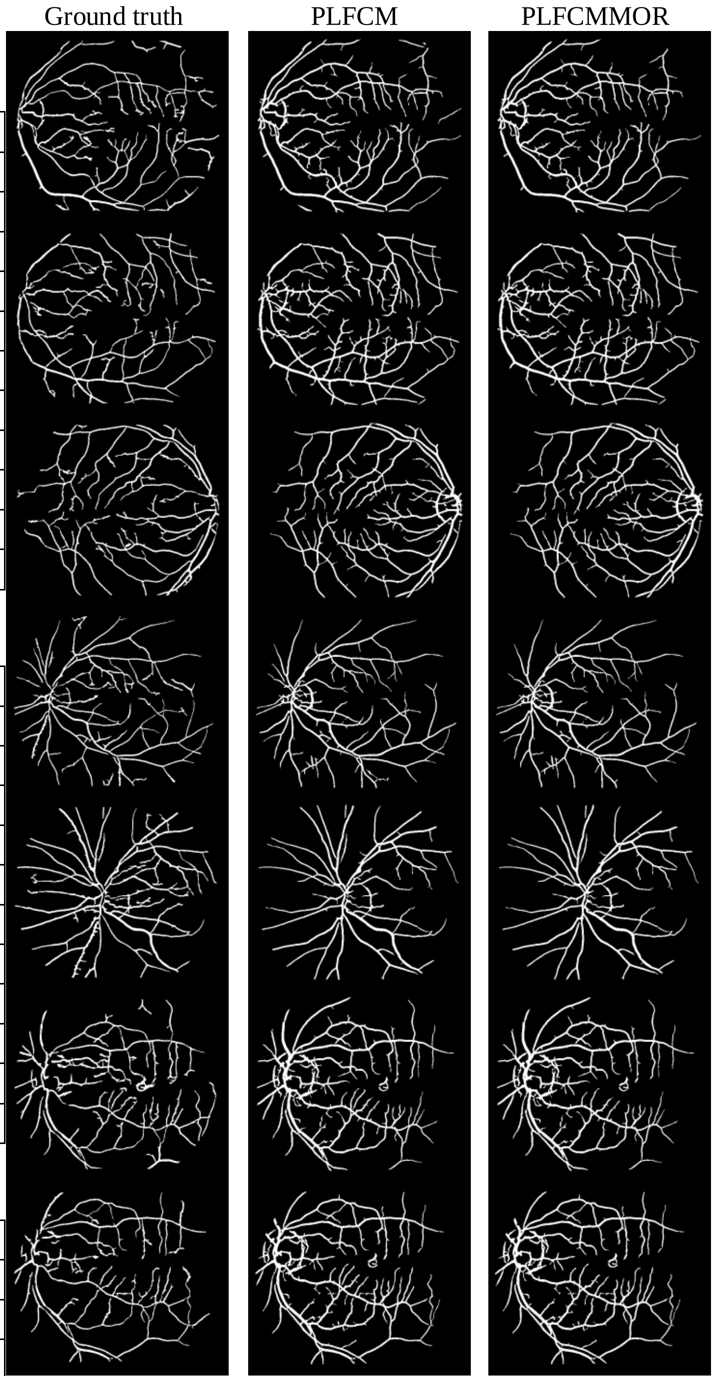
	Specificity	
	PLFCM	**PLFCMMOR**
Image1	0.958929	0.959882
Image2	0.953645	0.953997
Image3	0.965286	0.965286
Image4	0.964452	0.964891
Image5	0.963864	0.964091
Image6	0.95715	0.957788
Image7	0.954185	0.954187
Image8	0.967903	0.968052
Image9	0.965095	0.965206
Image10	0.958408	0.958408

Table 3: Performance metric (Accuracy)

	Accuracy	
	PLFCM	**PLFCMMOR**
Image1	0.985446	0.984436
Image2	0.992719	0.992718
Image3	0.988574	0.988573
Image4	0.986068	0.985302
Image5	0.977624	0.977623
Image6	0.981527	0.980842
Image7	0.979775	0.979172
Image8	0.979775	0.979172
Image9	0.984093	0.982431
Image10	0.989531	0.989531

Table 4: Average of metrics for STARE DATASET

	Sensitivity	**specificity**	**Accuracy**
PLFCM	8.353657	9.608917	9.845132
PLFCMMOR	8.341587	9.611789	9.8398



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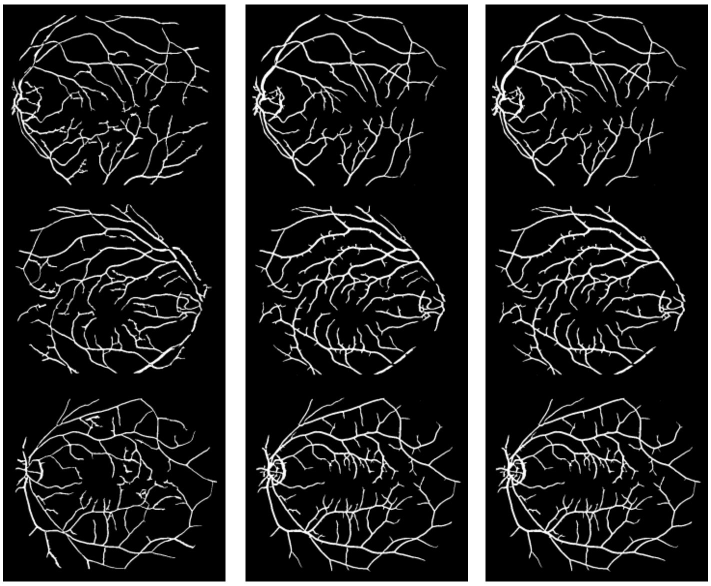

Fig. 5: Segmented blood vessels

IV. CONCLUSION

This manuscript has proposed a blood vessel segmentation algorithm using power law enhancement and FCM clustering. Power law enhancement is used to give more emphasis to the gray values of blood vessels and FCM clustering segments blood vessels from other regions. Once blood vessels are segmented, morphological operations are applied to eliminate unwanted and small segments of blood vessels. From the experiments, it is observed that improper selection of structural elements and size of structural elements may lead to elimination of blood vessels. Performance metrics such as sensitivity, specificity and accuracy also prove the effectiveness of the proposed method for the STARE dataset.

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