A review on Retinal Blood Vessel Segmentation Techniques

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Abstract— Segmentation of blood vessels from retinal images is a fundamental component in the procedure for detecting the status of Diabetic Retinopathy disease. Vision of the patients suffering from diabetes gets affected during the course of the disease from severe to extentive. Stage of the disease can be detected by observing the growth in blood vessels. For this purpose, one should be able to detect and segment the vessels effectively. The work done in this paper discuss the various segmentation algorithm designed over last two decades and compare them on the basis of performance metrics like acccuracy, sensitivity, specificity and area under curve. The main aim of this study is to provide an overview of the current research and future directions in the field of blood vessel segmentation from retinal images. This paper analyze, reviews and highlights the key points of the existing research and provide an open research issues which must be overcomed to improve the performance of the segmentation process and ultimately the detection of the disease.

Key words: Blood vessel segmentation; Retinal imaging, Diabetic retinopathy; Medical imaging Survey

I. INTRODUCTION

Diabetic retinopathy is caused by the leakage of fluids like proteins from the blood vessels in the retina due to which exudates are formed on the surface of retina. Initial stage of diabetic retinopathy includes dot hemorrhages and micro aneurysms on the surface of retina whereas in later stages, neovascularization i.e. growth of blood vessels, affect the visibility to a great extent. The disease is irreversible in nature and should be detected and cured at early stage. It has been shown that there are 80% chances that a patient affected from diabetes will suffer from diabetic retinopathy in about 10 years [1].

It has been concluded that manual segmentation is an error prone and a very time consuming process. Also it requires high level of expertise and skills. Medical community has now accepted that computer aided diagnosis system can provide better results. So, from last two or three decades CAD based detection and segmentation systems are being developed. Many studies have been proposed in order to improve the segmentation process of retinal blood vessels [2]. In this paper, a review of various methods proposed for blood vessel segmentation is done. Further comparison of these methods is shown on the basis of performance metrics like accuracy, sensitivity, specificity and area under curve. Several reviews and surveys have been done for the blood vessel segmentation techniques [3-6] but they are limited to some techniques. This paper aims to cover the different techniques on the basis of their segmentation procedure.

Rest of the paper is structured as follows: section II gives the detail of material used in retinal imaging. Section III discusses various segmentation methods with their advantages and disadvantages. Section IV provides the comparison of these techniques and finally the paper is concluded in section V.

II. MATERIAL AND METHOD

Popular datasets which are used for the evaluation of retinal blood vessel segmentation are DRIVE and STARE. In both datasets, images are divided into training and testing classes. Training class include the images with ground truth where the segmentation is done manually by the experts. This class is used to train the system that one has designed. Testing class include images which are to be tested to check the validation of the proposed system. Most of the work done in this field uses either of the two datasets or both.

DRIVE dataset [7] contain 40 images taken from the colour fundus camera Canon CR5. Resolution of image is kept fixed at 768*584 pixels and format in which images are stored is TIFF. Field of view for the camera is 45° which is approximately 540 pixels and is a non mydratic 3CCD camera. The images were obtained in a screening program held in Netherlands for retinopathy diabetic. There were 453 subjects with age greater than 30 years. From 40 images, seven images suffer from pathologies like epithelium change, hemorrhages and exudates. Images are equally divided into training and testing sets. Field of view masks for both the sets are also included. Testing set is divided further into set X and set Y. There are 577,649 pixels which are marked as vessels and 3,960,532 pixels which are marked as non-vessel in set X. In set Y, pixel marked as vessel is 556,532 and as non-vessel are 3,981,611 pixels.

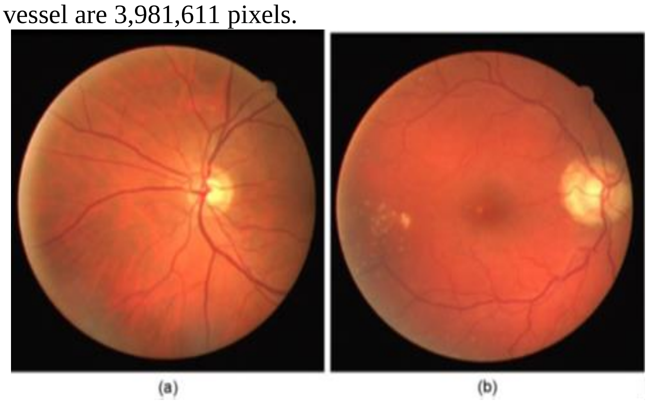

Fig. 1: DRIVE: (a) healthy image, (b) image with pathologies

STARE dataset [8] contain 20 images taken by TopCon TRV-50 camera. Resolution of images is kept at 700*605 pixels and the images are stored in a PPM format. Field of view for this dataset is 35°. Manual segmentation was done by two observers. One of them segmented 10.4% pixels as vessel while other has segmented 14.9%. The difference in the segmented pixels lies in the fact that second observer segmented more number of thinner vessels than the first one.

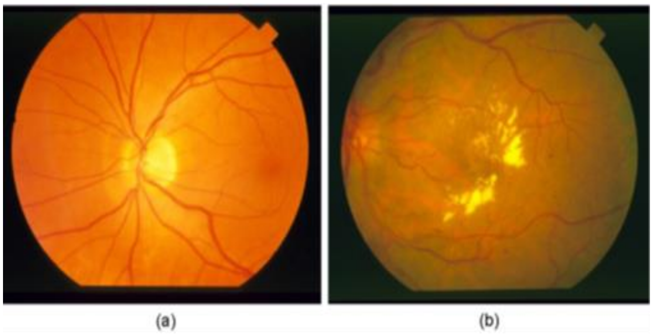

Fig. 2: Stare: (a) healthy image, (b) pathological image

III. REVIEW

One of the initial works done for the blood vessels detection and segmentation was introduced by chaudhuri et al. [9]. It calculates the gray level values in a direction perpendicular to that of blood vessel. Mean filter is firstly applied with a window of 5*5 to enhance the image before segmentation. To detect the orientation of blood vessels in different directions, 12 directions are selected ranging from 0° to 180° with an equal distance of 15°. A kernel is approximated for each of the 12 directions and highest response is selected for each pixel. The main advantage of this algorithm is that it can detect vessel in low contrast images also. On the other hand, edges of bright objects like optical disk; lesions etc. are also detected along with vessels. Another disadvantage of the proposed method is that it become complex in terms of computation with an increase in kernel size. The proposed method is also implemented in various fingerprint and satellite images for segmentation. It performs better that other popular edge detection based segmentation methods like sobel operator and morphological edge detector [2].

Ayala et al. [10] proposed a fuzzy rule based segmentation procedure for blood vessels from retinal images. Low level reprocessing was done to enhance the thin and light blood vessels before segmentation. For segmentation average distance and mean were taken as thresholding parameters. A binary vessel tree is obtained after the segmentation process using thresholding method. Final segmentation was done using fuzzy set of structured elements which is defined by the invariant length of blood vessels. A final image is obtained by the aggregation of average proposed for fuzzy set. Performance metrics used for the evaluation of the proposed algorithm are false positive rate and false negative rate. On observing the performance of the algorithm it was seen that there is decrease in false positive rate.

An improvement over the method proposed in [9] was proposed by Al-Rawi et al. [11] for blood vessel segmentation. The improvements are done by defining the optimal tuning parameter values. The proposed technique was applied on 20 images which were selected from DRIVE dataset. For filtering, two filters were used, namely OGMF and TSGMF. Parameters for OGMF were tuned at (L,_,T) =(10.8,1.9,8) and for TSGMF were (L1,_1,T1)=(10.8,1.9,8) and (L2,_2,T2)=(7.6,1.9,8). Maximum response is selected from the 24 filters and better results were shown by TSGMF. Evaluation of different methods is done using performance metrics like ROC curve and accuracy. Along with DRIVE dataset, the method was also applied to Hoover dataset and satisfactory results were obtained. Further it was proved that green channel is best suitable for response of matched filter than red and blue channel. Another issue related to threshold value was also discussed and it was found that Euler's number and connected components can obtain better results.

A wavelet transformation based blood vessel detection method was proposed by soares et al. [12]. 2-D Morlet Wavelet Transformation method was used in the proposed methodology as it is known for its optimal frequency tuning and variability in selecting orientations. Preprocessing is done before segmentation by replacing outer neighbor pixels by mean of inner neighbor pixels. After that features ware calculate and classification of pixels was done into vessel or non-vessel pixel. Orientations are divided by the difference of 10 ranging from 0 to 170. For each scale, morlet wavelet transform calculate the responses which are used as features along with pixel intensity. Best results were obtained when frequency was tuned at 20 for scales of 2,3,4,6 pixels. Bayesian classifier is used to classify the pixel as vessel or non-vessel. The results of the Bayesian classifier were compared with linear minimum squared error classifier and it is found that Bayesian classifier gives better results in terms of classification but lacks in fast processing. The proposed methodology was implemented on DRIVE and STARE datasets which are publicly available.

Chang et al. [13] proposed a technique called retinal blood vessel segmentation based on line and edge detector (RBVSLE), to improve the classification rate of vessel and non-vessel pixels. Firstly the green channel is selected from the image and enhancement is done using the maximum and minimum intensity values along with contrast values. After enhancement, canny edge detection method was used to make an edge map. The obtained edge map shows all the vessels. However, it was found that some pixels are misclassified. So to improve the classification rates, two thresholds were set to select the pixel as vessel or non-vessel. If the intensity of the pixel lies between the threshold values, then it is considered as vessel pixel, otherwise non-vessel. Maximum mean intensity is selected from the calculated intensities in eight directions. Like other methods, performance of RBVSLE was also tested on DRIVE and STARE datasets. Accuracy rate was used as a performance metric to evaluate the performance and high rates of 94.31 and 94.19 were obtained for STARE and DRIVE datasets respectively.

Akram et al. [14] introduced a wavelet based enhancement method for blood vessels. Authors believed that enhancement of an image is a most important step in detecting blood vessels because corrupted or noisy pixels can lead to inappropriate results. Various factors were found that can affect the purity of an image and these are contrast of vessel and background, bright objects like fovea, lesions, optical disc, etc., illumination and must be removed for better classification of pixels as vessel and non-vessel. For enhancement, Gabor filter was used because of its advantages of better performance over other method. However, it causes blurring which was removed by sharpening the image. The canny edge detection method was used to create the edge map of vessels. On observing edge map, it was found that some holes were left in between edges which were later filled using morphological operations. The proposed methodology was implemented on STARE dataset and better results were obtained when compared to the latest state of the art techniques.

An Ant Colony algorithm based approach for segmentation of blood vessels was discussed by Cinsdikici and Avdin [15]. Preprocessing of the image was done using morphological operations and contrast enhancements techniques. After preprocessing, matched filter was applied in parallel to Ant Colony Algorithm to extract the blood vessels. The final segmentation of blood vessels was obtained by adding the two images obtained in the above step. Length filtering is then used to get the complete vascular image of the retinal blood vessels. Performance of the proposed algorithm was evaluated on DRIVE dataset considering two performance metrics: Area under curve and Accuracy. It was seen that an average accuracy of 92.93% was achieved and area under curve as 94.07%. Disadvantage of this algorithm is that pathological areas are also segmented as blood vessels. Another drawback that was seen that the obtained vascular vessels are somewhat thick when compared with the ground truth.

Xu and Luo [16] proposed a vessel segmentation technique based on support vector machine classifier. Initially, green channel is selected from RGB retinal image and normalization is done to enhance the blood vessels. Before segmentation, morphological operations were used to remove the optical disk from the image. After that adaptive thresholding method was applied to segment the thick blood vessels. Then, original image is subjected for extraction of features using multiple scales wavelets. Thin blood vessels were extracted using line detectors. For each pixel excluding the pixels of thick vessels, a feature vector is constructed comprised of 12 features from the binary image. Then thin vessels are distinguished from other fragments with the help of SVM. A vessel tree is then obtained using hessian matrix and vessel tracking method for thin vessels. On evaluating the performance of the proposed method, it was found that an average accuracy of 93.28% was achieved for DRIVE dataset.

Feature-Based AdaBoost Classifier was introduced by Lupascu et al. [17] for segmentation of blood vessels. Various filters were used to remove noise and to enhance the image like matched filter, Gaussian filter and Gabor filters. Edges and ridges were approximated using surface intensity features like direction, gradient and mean curvatures. A total of 41 feature were extracted which include gray level, hessian measures, Guassian features and various shape features. A dataset of 189,914 pixels was used to train the AdaBoost classifier to classify them into vessel and non-vessel. On evaluating the performance of the algorithm it was seen that an average accuracy of 95.97% was achieved for DRIVE dataset. The main advantage of this algorithm lies in the fact that it can capture good information regarding structure and shape of blood vessels. However, it does not deal with the problem of broken vessels and missing pixels.

Amin and Yan [18] proposed a method for vessel segmentation using phase congruency technique. Initially a soft classification of blood vessels is done using phase congruency. Along with soft classification, change in the image contrast and luminosity is also recorded. Then Log-Gabor filter was applied to measure the phase congruency. After that, a binary image is created using the thresholding method which comprised of vessels. The obtained tree in binary image indicates the blood vessels. Algorithm was evaluated on DRIVE and STARE datasets. The performance of the proposed method was evaluated on the basis of accuracy and area under curve. Result shows that the algorithm has achieved an accuracy of 92% and 91% respectively for DRIVE and STARE dataset, while area under curve is as 94% and 92% respectively.

Sun et al. [19] proposed a watershed transformation based segmentation of retinal blood vessels. Nonlinear multi scale morphological operators were used to detect the background of the retinal image. The detected background is subtracted from the original image to obtain a contrast normalized image. Fuzzy morphological operations were used to process the contrast normalized image by combining it with 12 structuring elements which are ranged from 0° to 180° at an average difference of 15°. The length of the vessel for processing was set at nine pixel length. Then, thresholding algorithm is applied to segment out the blood vessel region from the image. For smoothening of the image and to fill the holes, thinning operation is applied. Finally, watershed segmentation algorithm was applied to segment the vessel. The proposed methodology was implemented on retinal images obtained from the seven patients. It was observed that Gaussian noise does not get affected by fuzzy filter.

Marin et al. [20] discussed a supervised methodology for blood vessel detection and segmentation using neural network. Improper illumination and vessel reflex problems are removed in preprocessing step. Like other studies, it also uses Gaussian kernel for smoothening of noise in an image. Then hat transformation technique based on morphological operations was used for the enhancement of the image. 7 features were extracted and stored in a feature vector. Out of 7 features, 2 are the Hu Invariant Moment features which ensure that the vessel detection will not be altered by orientation of the image or vessels and 5 features are selected from gray level based features. This feature vector was the fed to the classifier to classify the pixels of an image as vessel or non-vessel. Classifier used in this study is multilayer feed forward neural network which has shown promised results in field of pattern recognition. After classification, post processing was done to fill the holes between vessels pixels. Proposed methodology was implemented on STARE and DRIVE datasets and performance was measured on the basis of performance metrics like positive rate, negative rate and accuracy. An average of 94.89% accuracy was achieved which shows similar results as compared to other studies.

A gradient orientation based method for segmentation of blood vessels from retinal images was proposed by Onkaew et al. [21]. Due to its independence nature from gray level intensities, improper illumination or low contrast does not hinder the segmentation process. Firstly, gradient vectors are calculated for x and y directions using the derivative operator, which are then normalized for fast processing. The behavior of the unit gradient vectors depends on the features. Vector will diverge if features are brighter than the background and converge if they are darker. These unit vectors are comprised of linear and circular features which define the orientation of the vessel. Morphological and thresholding techniques were used to segment the blood vessels on the basis of extracted gradients. DRIVE and STARE datasets were used to evaluate the performance of the proposed methodology. Performance of 87.74% positive rate and 82.67% negative rate was achieved.

Drawback of this method was that it does not detect blobs or patches which reduce the accuracy of the algorithm.

Another SVM based semi supervised methodology for segmentation of blood vessels was introduced by You et al. [22]. For enhancement of thin and light vessels, a modified complex wavelet filter was used. A new radial projection technique was used for the first time in blood vessel segmentation which is used to locate the low contrast, narrow blood vessels and vessel centerlines. Then feature vector is calculated from the line strength measures. The generated feature vector is fed to the semi supervised SVM classifier which in turn extracted the vessel structure map. The final segmented vascular image is obtained by adding the two. The algorithm yield good results and reduce false positive results as it is self-training method. The proposed method performs well for thin and light vessels but average in case of pathologies. Performance was measured on DRIVE and STARE dataset and an average accuracy of 94.34% and 94.97% was achieved respectively.

Akram et al. [23] in his another study proposed a segmentation method for detection of proliferative diabetic retinopathy (PDR). In PDR, growth of new blood vessels starts which is known as neovascularization, and this growth in blood vessels affect the visibility of eyes. As in his earlier study, author used the Gabor wavelet filter for the enhancement of the image to enhance the thin and light vessels. The processing of the image was done in form of window with size 15*15. For each window, density and entropy was calculated respectively for each vessel. Then segmentation was done using multilayered thresholding method to segment the blood vessels. Performance of the proposed method was evaluated on DRIVE and STARE datasets and an accuracy of 94.69% and 95.02% was achieved respectively for DRIVE and STARE datasets.

Lazar et al. [24] in his study used directional height statistics to segment out the blood vessels from retinal images. Gaussian filter was used to enhance the thin and light vessels that range in between 0.5 standard deviation. Then a score map is created for each pixel which considered the values of mean and S.D. These scores are used to classify pixel as vessel and non-vessel. The idea of creating score map comes from the fact that a Gaussian like peak is generated when intensity is calculated in a direction perpendicular to blood vessels. Further, it was found that peak height is less for background pixels and more for vessel pixels. Higher the score value means that the pixel has higher probability of being a vessel pixel. A binary mask was then created to segment the blood vessels using Hysteresis thresholding method. Implementation was done on DRIVE dataset and an accuracy of 92.54% was achieved for parameter area under curve.

A rule based algorithm called Star Networked Pixel Tracking algorithm was proposed by Ocbagir et al. [25] for detection and segmentation of retinal blood vessels. For enhancement of blood vessels, morphological operations and adaptive histogram equalization techniques were used. After enhancement, noise was removed from the image using median filter. Then a pixel by pixel approach is followed in which a pixel is compared with neighbor pixels. The neighbor pixels are selected from a range of 45° to each other. A zero neighbor pixel indicates that the original pixel does not belong to vessel and if it is one, then it belongs to the vessel. The process continues until each and every pixel is processed. The directions are divided in the 8 sectors. In this way, all pixels are indexed as vessel or non-vessel and a vessel map is then created. After creating vessel map, standard deviation and intensity values are used for local enhancement. To extract the blood vessels, automatic thresholding method was used on the basis of formed vessel map. An accuracy of 95.83% was achieved when implemented on DRIVE dataset.

Mehrotra et al. [26] introduced a segmentation technique based on Kohonen Clustering Network. Firstly, noise is removed from the image for which two filters were used namely Gaussian filter and Novel Edge Preserving Filter to remove Gaussian noise and impulse noise respectively. Improper illumination was removed by equalization method. Image pixels are then determined from bottom and top Hat Transformations. Then Kohonen Clustering Network was used to cluster the pixels in two classes, one as vessel and another as non-vessel. Euclidean distance was used as a metric in the formation of clusters. Performance of the proposed methodology was evaluated on DRIVE dataset. A high accuracy rate of 98.02% was achieved, while false positive rate was 4.15%.

One of the latest works was proposed by Bhatia et al. [27], which is an efficient supervised method for the segmentation of blood vessels. Firstly the green channel is selected from the RGB retinal image obtained by the fundus camera. Green channel has been proved to show best contrast combination between the blood vessels and the background of the image than the other two channels which show more noise. Then enhancement techniques were applied to enhance the thin and light blood vessels. Enhancements techniques include uneven illumination correction, Gaussian filter, adaptive histogram equalization and normalization. Then edges were detected using the canny edge detection method. Morphological operation finally segment out the required blood vessels from the image. The proposed algorithm was evaluated on the basis of average accuracy for DRIVE and STARE datasets. It was shown that an average accuracy of 95.23% has been achieved, while sensitivity values are 70.31% and 95.23% respectively for DRIVE and STARE datasets.

IV. COMPARISON

Author	Dataset	Accuracy	Sensitivity	Specificity	Area under curve
Chowdhuri et al. (1989)	DRIVE	87.73 %	---	---	78.78 %
Al-Rawi et al. (2006)	DRIVE	95.35 %	---	---	94.35 %
Soares et al. (2006)	DRIVE STARE	94.67 % 94.74 %	---	---	95.98 % 96.51 %

Chang et al. (2009)	DRIVE STARE	94.19% 94.31%	---	---	---
Akram et al. (2009)	STARE	94.39%	---	---	---
Cinsidikici et al. (2009)	DRIVE	92.93%	---	---	94.07%
Xu et al. . (2010)	DRIVE	93.28%	77.60%	---	---
Lupascu et al. (2010)	DRIVE	95.97%	72%	---	95.61%
Amin et al. (2010)	DRIVE	92%	---	---	94%
Marin et al. (2011)	DRIVE STARE	94.52% 95.26%	70.67% 69.44%	98.01% 98.19%	95.88% 97.69%
Inkaew et al. (2011)	STARE	---	87.74%	82.67%	---
You et al. (2011)	DRIVE STARE	94.34% 94.97%	74.10% 72.60%	97.51% 97.56%	---
Akram et al. (2012)	DRIVE STARE	94.69% 95.02%	---	---	---
Lazar et al. (2012)	DRIVE	---	76.50%	96.70%	---
Ocbagir et al. (2013)	DRIVE	95.83%	71.31%	98.24%	---
Mehrotra et al. (2014)	DRIVE	98.02%	---	---	---
Bhatia et al. (2015)	DRIVE STARE	95.48% 94.98%	64.29% 76.33%	98.59% 96.11%	---

Table 1:

V. CONCLUSION

Segmentation of blood vessels is an important task for the detection of diabetic retinopathy. Improper segmentation can lead to false detection of the disease due to which patient can lose eye sight. On the other hand, effective and efficient segmentation can result in detection of disease at early stage. There are many hurdles in the segmentation of blood vessels like optical disk, exudates, hemorrhage, macula etc., which can decree the overall accuracy of the segmentation process. Many such algorithms have been developed which segments the vessels from retinal image. A major step in this process is the enhancement of thin and light vessels which are remain undetected in most of the studies. Also the accuracy of segmentation can be increased by considering more factors like contrast etc. This study is aimed at providing basic idea of how much research has been done in this field and what more can be done to improve the segmentation process.

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