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Review on Blood Vessel Segmentation Techniques in Retinal Images

Sivakami D[1] and Swarnalatha N[2]
[1,2]Lecturer (Sr. Gr.)
[1]Department of Instrumentation and Control Engineering, [2]Department of Computer Engineering
A.D.J. Dharmambal Polytechnic College
Nagapattinam
{ sivakamiasok, nslatha70 }@gmail.com

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ABSTRACT. *The blood vessel extraction is an important process in automatic eye diagnostics using retinal images. Traditionally, the vasculature segmentation is one of the steps in various retinal disease diagnostics. This paper examines the various techniques of blood vessel segmentation in retinal images. The objective is to review the various techniques of blood vessel extraction and categorize them based on algorithms and dataset, and to analyze them based on various performance measures such as accuracy, sensitivity, specificity, and sensibility. DRIVE, STARE, Messidor, ImageRet, ARIA Online, Review, VICAVR and ROC microaneurysm set are the database which are used in literature. A brief information about these datasets are presented in this paper. Most of the work has been concentrated on DRIVE and stare database, and hence those results are summarized.*

Keywords: Blood vessel, medical imaging, segmentation, performance measures.

1. **Introduction.** Retinal blood vessel segmentation provides various information that attributes to the automatic disease diagnostic systems. It helps in screening and treatment of various ophthalmic diseases such as diabetic retinopathy, hypertension, and retinitis pigmentosa [1]. Despite being used in diagnostics, the blood vessel tree of each person is unique and hence the blood vessel extraction could also be used for biometric identification. Fundus camera is used for the retinal photography. The images are captured either in dilated or non-dilated mode. Also, the images could be captured using fluorescein angiography. The retinal images are basically characterized by important components such as optic disc, optic cup, blood vessels, exudates, and pigments [2] as shown in Figure 1. The vessels consist of arteries and veins, the width of which varies from one pixel to twenty pixels based on its nature. The cross section of the vessel matches with the Gaussian shape and hence the Gaussian filter could also be used for the extraction of blood vessels [3]. The blood vessels are the connected regions and appear to be darker than the background region. But there are certain other regions which are similar in intensity to that of the blood vessels which makes the extraction process difficult. The connected feature of blood vessels

can be used for construction of vascular tree which could be used in biometric identification.

Throughout the literature there are various manual segmentation techniques which are complex and tedious tasks which requires huge effort for implementation. Thus, automatic diagnosis using computer assisted techniques are the simple and easy one. The first step in the computer assisted automatic diagnostics is the blood vessel extraction for various ophthalmic diseases. This paper gives a brief review on all the various techniques that could be used for the blood vessel extraction. The various publicly available retinal datasets are discussed in detail. Also, the techniques used in various works are segregated based on the nature of algorithms used. A comparison on the various methodologies for similar dataset is made based on the performance metrics.

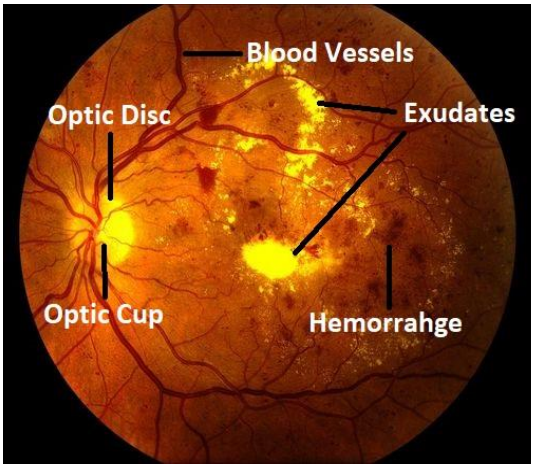

Figure1. Retinal image showing various morphological features

Further, the paper is organized in the following manner. Section 2 discusses about the various publicly available datasets and its information. The classification of segmentation techniques is briefly discussed in Section 3. Section 4 gives the comparison of various techniques based on the performance metrics. Finally, the conclusion is illustrated in Section 5.

2. **Retinal Image Dataset.** Fundus cameras are used for acquiring the retinal images, which captures the interior surface along with the retina, optic disk, posterior pole and macula. The image could be captured in three modes such as color photography, red-free photography, and fluorescence angiogram. The color photography is acquired using white light illumination, whereas the red-free image obtained by filtering out the red color from the image. The fluorescent angiogram is obtained using the dye tracing method. There are wide range of publicly available retinal datasets which includes DRIVE dataset, STARE dataset, Messidor, ImageRet, AIRA online, Review, VICAVR dataset, and ROC microaneurysm set. The complete information about these datasets are tabulated in the Table 1.

TABLE 1: Information about the publicly available datasets

S.No	Dataset	Year	No. of images	Resolution	Camera used of capturing	Ground truth information	Observer results
1.	DRIVE (Digital Retinal Images for Vessel Extraction) [4]	2004	40 images 453 subjects 20 – testing 20 – training 7 – pathology	768×584	Canon CR5 non-mydriatic 3-CCD camera FOV – 45˚	Yes (for 20 training images)	12.7% vessels in set X and 12.3% vessels in set Y
2.	STARE [5]	2000	20 images 10 – pathology	605×700	TopCon TRV-50 fundus camera FOV – 35 ˚	Yes	10.4% vessels by first observer and 14.9% vessels by second observer
3.	Messidor [6]	2014	1200 images	1440×960 2240×1488 2304×1536	Non-mydriatic 3CCD camera (Topcon TRC NW6) FOV - 45 ˚	No	-
4.	ImageRet [7]	2008	DIARETDB0 130 images 20 – normal 110 - pathology DIARETDB1 89 images 5 – normal 84 – pathology	1500×1152	FOV - 50 ˚	Yes	Four experts marked microaneurysms, hemorrhages, hard and soft exudates.
5.	AIRA online [8]	2006	92 – age macular degeneration 59 – diabetes 61 - normal	768×576	Zeiss FF450+ fundus camera FOV - 50 ˚	Yes	Two experts marked blood vessels, optic disc and fovea.
6.	Review (Retinal Vessel Image set for Estimation of Widths) [9]	2008	16 images 8 – high resolution image set 4 – vascular disease image set 2 – central light reflex image set 2 – kickpoint image set	-	-	Yes	193 annotated blood vessel segments marked by three experts
7.	VICAVR database [10]	-	58 images	768×584	Topcon non-mydriatic camera NW-100 model	Yes	It contains vessel type information such as artery or vein marked by three experts.

8.	ROC microaneurysms set [11]	2009	100 images 50 – training 50 – testing	768×576 1058×1061 1389×1383	Topcon NW100 or Canon CR5-45NM camera FOV - 45 °	Yes	The location of microaneurysms for training images is provided.

3. **Classification of Blood Vessel Segmentation Techniques.** There are different types of techniques used for blood vessel segmentation such as pattern recognition techniques, tracking based techniques, neural network based techniques, region based techniques, and model based techniques. They include supervised methods, unsupervised methods, matched filtering method, morphological processing, vessel tracking, and multiscale approaches. This section reviews the various papers that uses these techniques and compares them based on performance metrics.

3.1. **Supervised and Unsupervised methods.** Using pattern recognition, the blood vessel extraction methods broadly fall in the category of supervised and unsupervised methods. The extraction is done using the learning algorithms using the training data. Neimeijer et. al. [12] used the green channel image and matched it with the gaussian matched filter and its first and second order derivates, after which the k-Nearest Neighbour algorithm is applied. Staal et. al. [13] presented image ridges and k-NN classifier for the blood vessel extraction. Nekovei et. al. [14] presented a back-propagation mechanism of neural network. Osareh et. al. [15] used the Multiscale Gabor filter and GMM classifier for the blood vessel extraction. Martin et. al. [16] used 7-D feature vector and a multilayer feed forward neural network for blood vessel extraction. The performance measures of supervised methods are illustrated in the Table 2.

Table 2: Performance measures of supervised methods

Author	Database	ACC	SEN	SPF
Nekovei et. al.	DRIVE	0.9416	0.7145	-
Staal et. al.	DRIVE STARE	0.9442 0.9516	- -	- -
Osareh et. al.	DRIVE	-	-	-
Martin et. al.	DRIVE STARE	0.9452 0.9526	0.7067 0.6944	0.9801 0.9819
Ground Truth	DRIVE STARE	0.9470 0.9348	0.7763 0.8951	0.9723 0.9384

In case on unsupervised methods, Salem et. al. [17] presented a Radius based clustering algorithm for segmentation. Ng et. al. [18] used maximum likelihood estimation of scale space parameters. Kande et. al. [19] presented a method using spatially weighted fuzzy C-means clustering. The performance metrics of these methods are presented in Table 3.

Table 3: Performance measures of unsupervised methods

Author	Database	ACC	SEN	SPF
Salem et. al.	STARE	-	0.8215	0.9750
Ng et. al.	STARE	-	0.7000	0.9530
Kande et. al.	DRIVE STARE	0.8911 0.8976	-	-
Ground Truth	DRIVE STARE	0.9470 0.9348	0.7763 0.8951	0.9723 0.9384

3.2. **Multiscale approach for blood vessel extraction.** In wavelet decomposition each scale contains its own information. The blood vessel width decreases as it goes away from the optic disc region. This information regarding the blood vessels would be obtained from one scale of decomposition [20]. Anzalone et. al. [21] presented a vessel segmentation using red-free image using scale space theory. It defines optimum scale factor and threshold for segmentation. Perez et. al. [22] used a likelihood test for centreline extraction from the vessels. The multiscale MF is used for segmenting the vessels of varying width. Vlachos et. al. [23] demonstrated line tracking in multi-scale domain for blood vessel segmentation. The performance metrics of multi-scale approach for vascular segmentation is illustrated in Table 4.

Table 4: Performance measures of multiscale approach for blood vessel segmentation

Author	Database	ACC	SEN	SPF
Anzalone et. al.	DRIVE	0.9419	-	-
Perez et. al.	DRIVE STARE	0.9344 0.9410	0.7246 0.7506	0.9655 0.9569
Vlachos et. al.	DRIVE	0.9290	0.747	0.955
Ground Truth	DRIVE STARE	0.9470 0.9348	0.7763 0.8951	0.9723 0.9384

3.3. **Vessel tracking method.** The vessel tracking, or tracing is done through the center line of the blood vessel. The varying width of the blood vessels does not affect this approach, since it is based on the centerline. The tracking involves the following of the center line which is guided by the local information. Such methods provide accurate results and is used in the construction of vascular tree. The vessel tracing algorithm is used along with morphological processing or matched filter. There are various vessel tracing algorithms such as adaptive tracking, algorithm to track the centerline and to find the diameter, tracing using Gaussian and Kalman filters, wave propagation and traceback mechanism, and recursive tracking of vessels from seed points using direction map.

3.4. **Matched filtering.** Vascular convolution of 2-D kernel image with retinal image constitutes the matched filter implementation. The three basic assumptions [24] in matched filtering are as follows:

- The vessels can be approximated as piecewise linear segments, as they have limited curvature,
- The thickness of the vessels decreases as it propagates away from the optic disc, and
- The cross-sectional intensity of pixel can be approximated as Gaussian distribution.

Al-Rawi et. al. [25] used the improved gaussian matched filter by exhaustive optimization. Amin et. al. [26] proposed used phase congruency for high speed detection of blood vessels. Cinsdiki et. al. [27] demonstrated a hybrid of matched filter together with ANT colony algorithm for vascular segmentation. 2-D Gaussian matched filter technique is proposed by Yao et. al. [28] which simplified pulse coupled neural network. Chaudhuri et. al. [29] used two-dimensional linear kernel together with Gaussian for blood vessel extraction. The performance metrics of matched filter type detection of the blood vessel is tabulated in Table 5.

Table 5: Performance measures of matched filter type detection of blood vessels

Author	Database	ACC	SEN	SPF
Al-Rawi et. al.	DRIVE	0.9535	-	-
Amin et. al.	DRIVE	0.9200	-	-
Cinsdikici et. al	DRIVE	0.9293	-	-
Yao et. al.	STARE	-	0.8035	0.9720
Chaudhuri et. al.	DRIVE	0.8773	-	-
Ground Truth	DRIVE STARE	0.9470 0.9348	0.7763 0.8951	0.9723 0.9384

3.5. **Morphological processing.** The extraction of morphological features that provide useful information is regarded as the morphological processing. Morphological operations use structuring element which could be applied to both binary and grayscale images. The operation includes dilation and erosion. Zana et. al. [30] used the combination of cross curvature evaluation and morphological filter for vascular segmentation. Ayala et. al. [31] used average distance by Baddeley et. al. [32] for defining an average fuzzy set for blood vessel extraction. Sun et. al. [33] proposed a technique with the combination of morphological multiscale enhancement, fuzzy filtering, and watershed transformation for the vascular extraction. The performance metrics of morphological techniques are listed in Table 6.

Table 6: Performance measures of morphological processing for vascular segmentation

Author	Database	ACC	SEN	SPF
Zana et. al.	DRIVE	0.9377	0.6971	-
M.M Fraz et. al. [34]	DRIVE STARE	0.9430 0.9442	0.7152 0.7311	0.9769 0.9680
Mendonca et. al [35]	DRIVE STARE	0.9452 0.9440	0.7344 0.6996	0.9764 0.9730
Ground Truth	DRIVE STARE	0.9470 0.9348	0.7763 0.8951	0.9723 0.9384

4. **Performance Metrics and Discussions.** The performance metrics of the various algorithms are calculated using accuracy (ACC), sensitivity (SEN), specificity (SPF), TPR, and FPR [36]. They are demonstrated using the true positive (TP), true negative (TN), false positive (FP), and false negative (FN) values as shown below:

Accuracy (ACC)	(TP+TN)/(TP+TN+FP+FN)
Sensitivity (SEN)	TP/(TP+FN)
Specificity (SPF)	TN/(TN+FP)
TPR	TP/Vessel pixel count
FPR	FP/Non-vessel pixel count

Thus, it could be observed that in DRIVE database the technique proposed by Martin et. al. seems to be performing well among other supervised learning methods. Salem et. al. works well among other unsupervised methods with respect to specificity and accuracy. In multi-scale approach Anzalone et. al. results seem to be convincing than other multi-scale approaches. Al-Rawi et. al. in matched filter type detection performs well for DRIVE dataset. In case of morphological processing, Mendonca et. al. results are better for DRIVE dataset. For STARE dataset, Staal et. al. performs well in supervised methods with respect to accuracy and Perez et. al. results are better in case of unsupervised methods. Yao et. al. performs well among other matched filter methods, and M.M. Fraz et. al. results better than other morphological processing techniques.

5. **Conclusion.** The paper reviews and analyses various retinal datasets, and vascular segmentation methodologies. The methodologies are evaluated for DRIVE and STARE datasets. The methods are segregated as different types based on the nature of segmentation. In each case, the best performing algorithm is studied. Overall it is observed that Al-Rawi et. al. method using matched filter type vascular segmentation is performing well with the accuracy of 0.9535. Also, it is observed that the DRIVE dataset is performing better than STARE for almost all the methodologies taken into consideration. It is also observed the further investigation on multiscale analysis using wavelength decomposition could give exact information about the blood vessels.

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