Retinal Image Blood Vessel Segmentation

M. Usman Akram, Anam Tariq, Shoab A. Khan

Abstract—**The appearance and structure of blood vessels in retinal images play an important role in diagnosis of eye diseases. This paper proposes a method for segmentation of blood vessels in color retinal images. We present a method that uses 2-D Gabor wavelet to enhance the vascular pattern. We locate and segment the blood vessels using adaptive thresholding. The technique is tested on publicly available DRIVE database of manually labeled images which has been established to facilitate comparative studies on segmentation of blood vessels in retinal images. The proposed method achieves an area under the receiver operating characteristic curve of 0.963 on DRIVE database**.

I. Introduction

Diabetic eye disease refers to a group of eye problems that people with diabetes may face as a complication. Patients with diabetes are more likely to develop eye problems such as cataracts and glaucoma, but the disease's affect on the retina is the main threat to vision [1]. One of the complications of abnormalities in the retina and in the worst case blindness or severe vision loss is called Diabetic Retinopathy [1].

Non-proliferative retinopathy is the less serious form of diabetic retinopathy and occurs when an abnormality develops in the retinal capillaries, allowing fluid to leak into the tissue of the eye. In this condition, a network of small blood vessels, called choroidal neovascularization (CNV), arises in the choroid and taking a portion of the blood supplying the retina. As the amount of blood supplying the retina is decreased, the sight may be degraded and in the severe cases, blindness may occur [2]. The most common signs of diabetic retinopathy include hemorrhages, cotton wool spots, dilated retinal veins, and hard exudates [3-8].

Retinal images, also known as fundus or ocular images are acquired by making photographs of the back of the eye. We are interested in vessel enhancement and segmentation for screening of diabetic retinopathy. Eye care specialists can screen large populations for vessel abnormalities after the development of an efficient and effective computer based approach to the automated segmentation of blood vessels in retinal images.

M. Usman Akram is with department of Computer Engineering, College of E&ME, NUST, Rawalpindi, Pakistan; (e-mail: usmakram@ gmail.com).

Anam Tariq is with department of Software Engineering, Fatima Jinnah Women University, Rawalpindi, Pakistan; (e-mail: anam.tariq86@gmail.com).

Shoab A. Khan is with department of Electrical Engineering College of E&ME, NUST, Rawalpindi, Pakistan; (e-mail: shoab@carepvtltd.com.pk).

The detection and measurement of blood vessels can be used to classify the severity of disease, as part of the process of automated diagnosis of disease or in the assessment of the progression of therapy [9]. Retinal blood vessels have measurable changes in diameter, branching angles, length, as a result of a disease. Thus a reliable method of blood vessel extraction and segmentation would be valuable for the early detection and characterization of changes due to such diseases [9].

Computerized and automated segmentation provides consistency and reduces the time required by a physician or a skilled technician for manual labeling [1]. Retinal vascular pattern is used for automatic generation of retinal maps for the treatment of age-related macular degeneration [10], extraction of characteristic points of the retinal vasculature for temporal or multimodal image registration [11], retinal image mosaic synthesis, identification of the optic disc position [12], and localization of the fovea [13].

The challenges faced in automated vessel detection include wide range of vessel widths, low contrast with respect with background and appearance of variety of structures in the image including the optic disc, the retinal boundary and other pathologies [14]. Methods based on vessels tracking to obtain the vasculature structure, along with vessel diameters and branching points have been proposed by [15]-[20]. Tracking consists of following vessel center lines guided by local information. In [21], ridge detection was used to form line elements and partition the image into patches belonging to each line element. Pixel features were then generated based on this representation. Many features were presented and a feature selection scheme is used to select those which provide the best class separability. Papers [22]-[25] used deformable models for vessels segmentation. Chuadhuri et al. [26] proposed a technique using matched filters to emphasize blood vessels. An improved region based threshold probing of the matched filter response technique was used by Hoover et al. [27].

In this paper, we present the automated vessel segmentation technique for colored retinal image that enhances the vascular pattern using 2-D Gabor wavelet. Our technique creates a binary mask for vessel segmentation applying adaptive thresholding on enhanced retinal image. We compare our results with two methods, Staal et al. [21] and Soarse et al. [31] for DRIVE [33] database.

The paper is organized in four sections. In Section II, a schematic overview of our implementation methodology is illustrated. Section II also presents the step by step techniques required for automated vessel segmentation

978-1-4244-4609-4/09/$25.00 ©2009 IEEE

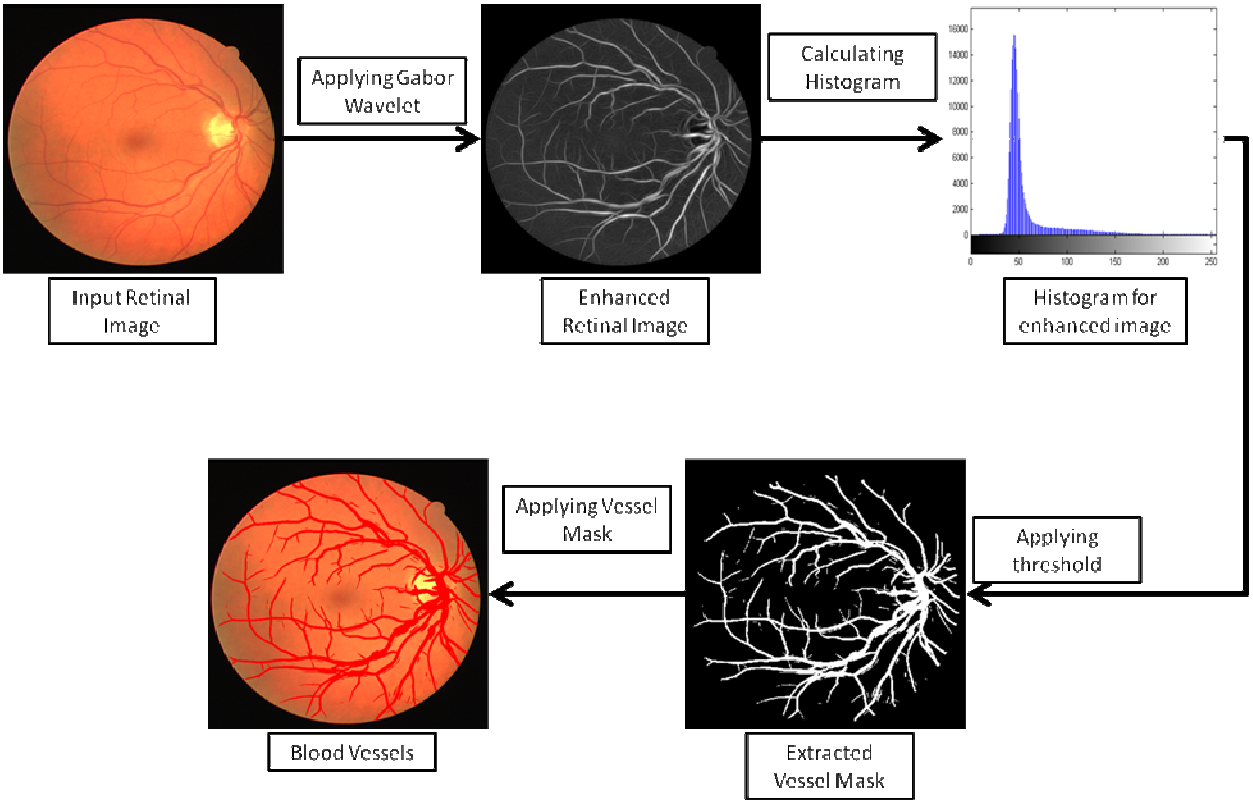

Fig. 1. Complete flow diagram for vessel segmentation system

and screening system. Experimental results of the tests on the images of the DRIVE database and their analysis are given in Section III followed by conclusion in Section IV.

II. Proposed System

Automatically locating the accurate vascular pattern is very important in implementation of vessel screening system. An automated vessel screening system to facilitate the specialists is an application of consumer electronics. Our proposed method segments the blood vessels from retinal images with great accuracy as compared to previous techniques. In proposed method, the monochromatic RGB retinal image is taken as an input and 2-D Gabor wavelet is used to enhance the vascular pattern especially the thin and less visible vessels are enhanced using Gabor wavelet [28].

Vessels segmentation binary mask is created by thresholding the enhanced retinal image. The blood vessels are marked by the masking procedure which assigns one to all those pixels which belong to blood vessels and zero to non vessels pixels.

Figure 1 shows the complete flow diagram for designing an automated vessel screening system using proposed blood vessel segmentation technique.

We have used 2-D Gabor wavelet to enhance the vascular pattern and thin vessels [28]. 2-D Gabor wavelet is used due to its directional selectiveness capability of detecting oriented features and fine tuning to specific frequencies [28], [30].

a) The continuous wavelet transform Tψ (b, θ, a) is defined in terms of the scalar product of f with the transformed wavelet ψ_b,θ, a using equation 1 [31]

$$T_\psi(b,\theta,a) = C_\psi^{-1/2}\left\langle \psi b,\theta,a \mid f\right\rangle$$
$$= C_\psi^{-1/2} a^{-1}\int \psi * (a^{-1} r_{-\theta}(x-b)) f(x) d^2x \qquad (1)$$

where $f \in L^2$ is an image represented as a square integral (i.e., finite energy) function defined over R^2 and $\psi \in L^2$ be the analyzing wavelet. C_ψ, ψ, b, θ and a denote the normalizing constant, analyzing wavelet, the displacement vector, the rotation angle, and the dilation parameter respectively.

b) It is easy to implemented wavelet transform using the fast Fourier transform algorithm. Fourier wavelet transform is defined using equation 2 [26].

$$T_\psi(b,\theta,a) =$$
$$C_\psi^{-1/2} a \int \exp(jkb)\hat{\psi}^*(a r_{-\theta} k)\hat{f}(k) d^2k \qquad (2)$$

where $j = \sqrt{-1}$ and the hat ($\hat{\psi}^*$ and $\hat{f}$) denotes a Fourier Transform.

c) The 2-D Gabor wavelet is defined as [27]

$$\psi_G(x) = \exp(jk_0x)\exp(-\frac{1}{2}|Ax|^2) \quad (3)$$

where k_0 is a vector that defines the frequency of the complex exponential and $A = \mathrm{diag}[\varepsilon^{-1/2}, 1]$, $\varepsilon \geq 1$ is a 2×2 diagonal matrix that defines the elongation of filter in any desired direction.

d) For each pixel position and considered scale value, the Gabor wavelet transform M_ψ (b, a) is computed using equation 4 [26], for θ spanning from 0^o up to 170^o at steps of 10^o and the maximum is taken.

$$M_\psi(b,a) = \max_\theta |T_\psi(b,\theta,a)| \quad (4)$$

This gives us the enhanced vascular pattern for the retinal image. Histogram for the enhanced retinal image is calculated. Maximum values occur for the grayish background while the vessel corresponds to values a slight greater than the background values as they are of bright color. An adaptive thresholding technique is used that selects this point which separates the vessels from the rest of image. Vessel segmentation mask is created by applying this threshold value (Fig. 1).

III. EXPERIMENTAL RESULTS

The tests of proposed technique are performed with respect to the vessel segmentation accuracy using publicly available DRIVE [33] database. The images are of size 768×584 pixels, eight bits per color channel. Retinal image dataset is divided into a test and training set and each one contains 20 images. The test set is used for measurement of performance of the vessel segmentation algorithms. There are two hand-labeling available for the 20 images of test set made by two different human observers. The manually segmented images by 1st human observer are used as ground truth and the segmentations of set B are tested against set A, serving as a human observer reference for performance comparison truth [27], [31]. The true positive fraction is the fraction of number of true positive (pixels that actually belong to vessels) and total number of vessel pixels in the retinal image. False positive fraction is calculated by dividing false positives (pixels that don't belong to vessels) by total number of non vessel pixels in the retinal image. We compared the accuracy of proposed technique with the accuracies of the methods of Staal et al. [21] and Soares et al. [31]. Figure 2 illustrates the blood vessel segmentation results for proposed method against manually segmented set B for DRIVE database.

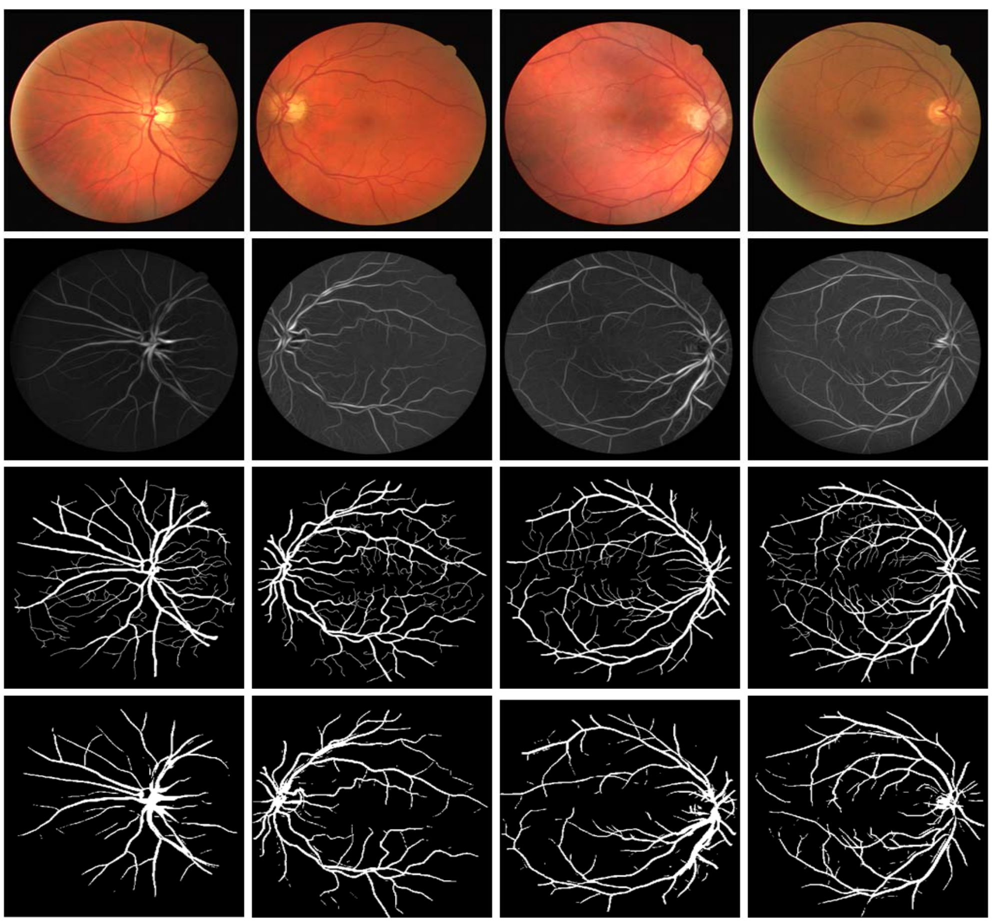

Fig. 2. Proposed technique results and manual segmentation set B for four images from the DRIVE database. Row 1: Original retinal images from dataset; Row 2: Enhanced retinal images using gabor wavelet; Row 3: Set B manual segmentation results; Row 4: Segmentation results for proposed technique

Table I summarizes the results of vessel segmentation for DRIVE database. It shows the results in term of Az, average accuracy and their standard deviation for different Segmentation methods and a second human observer. Az indicates the area under the receiver operation characteristics curve and accuracy is the fraction of pixels correctly classified.

TABLE I
VESSEL SEGMENTATION RESULTS (DRIVE IMAGES)

Segmentation Methods	A_z	Average Accuracy	Standard Deviation
2nd Observer	**-**	**0.9473**	**0.0048**
Staal et al.	0.9520	0.9441	0.0079
Soares et al.	0.9614	0.9466	0.0055
Proposed Method	**0.963**	**0.9469**	**0.0053**

IV. CONCLUSION

The proposed 2-D Gabor wavelet based approach for automated blood vessel segmentation is effective to handle vessel images under various conditions with reasonable accuracy and reliability for medical diagnosis. The problem with retinal images is that the visibility of vascular pattern is usually not good. So, it is necessary to enhance the vascular pattern. In this paper, vessels are enhanced prior to their detection. Vessel segmentation mask is created by applying thresholding. We have tested our technique on publicly available DRIVE database of manually labeled images. The experimental results demonstrated that our method performs well in detecting vessels and also efficiently enhances and segments the vascular pattern

ACKNOWLEDGMENT

The authors would like to thank J. V. B. Soares et al. for making their database publicly available.

REFERENCES

[1] E. J. Susman, W. J. Tsiaras, and K. A. Soper, "Diagnosis of diabetic eye disease," JAMA, vol. 247, pp. 3231-3134, 1982.
[2] J. KansKy, "Clinical Opthalmology, Butterworh-Heinmann," London, 1994.
[3] A.R. Bhavsar., "Diabetic retinopathy, The diabetes eye exam initiative," Minn Med., vol. 85, no. 6, pp. 46-47, Jun. 2002.
[4] N. Younis, D.M. Broadbent, S.P. Harding, and J.P. Vora, "Prevalence of diabetic eye disease in patients entering a systematic primary care-based eye screening programme," Diabet Med., vol. 19, pp.1014-1021, 2002.
[5] S.H. Sinclair, and C. Delvecchio, "The internist's role in managing diabetic retinopathy: screening for early detection," Cleveland Clin J. Med., Vol. 71, No. 2, pp.151-159, Feb.2004.
[6] J. Cavallereno , and L.M. Aiello, " Emerging trends in ocular telemedicine: the diabetic retinopathy model'" J Telemed & Telecare., vol. 11, pp.163-166, 2005.
[7] R.M. Davis, S. Fowler, K. Bellis, J. Pocki, V.A. Pakalnis, and A. Woldorf, " Telemedicine improves eye examination rates in individuals with diabetes," Diabetes Care, vol.. 26, no. 8, pp. 2476, Aug. 2003.
[8] S. Lightman, and H.Towler, "Diabetic retinopathy," Clin Cornerstone, vol. 5, no. 2: pp.12- 21, 2003
[9] M. E. Martnez-Prez, A. D. Hughes, S. A. Thom, A. A. Bharath and K. H. Parker, "Retinal Blood Vessel Segmentation by Means of Scale-Space Analysis and Region Growing", Medical Image Computing and Computer-Assisted Intervention MICCAI99, pp. 90-97, 1999.
[10] A. Pinz, S. Bernogger, P. Datlinger and A. Kruger, "Mapping the human retina," IEEE Trans. Med. Imag., vol. 17, no. 4, pp. 606-619, Aug. 1998.
[11] C.L. Tsai, C. V. Stewart, H. L. Tanenbaum and B. Roysam, "Modelbased method for improving the accuracy and repeatability of estimating vascular bifurcations and crossovers from retinal fundus images," IEEE Trans. Inf. Technol. Biomed., vol. 8, no. 2, pp. 122-130, Jun. 2004.
[12] M. Foracchia, E. Grisam, and A. Ruggeri, "Detection of the optic disc in retinal images by means of a geometrical model of vessel structure," IEEE Trans. Med. Imag., vol. 23, no. 10, pp. 1189-1195, Oct. 2004.
[13] H. Li and O. Chutatape, "Automated feature extraction in color retinal images by a model based Approach," IEEE Trans. Biomed. Eng., vol. 51, no. 2, pp. 246-254, Feb. 2004.
[14] A. M. Mendona, and A. J. Campilho, "Segmentation of Retinal Blood Vessels by Combining the Detection of Centerlines and Morphological Reconstruction." IEEE Trans. Med. Imag., vol. 25, no.9, pp.1200-1213, Sep. 2006
[15] I. Liu and Y. Sun, "Recursive tracking of vascular networks in angiograms based on the detection-deletion scheme," IEEE Trans. Med. Imag., vol. 12, no. 2, pp. 334-341, Jun. 1993.
[16] L. Zhou, M. S. Rzeszotarski, L. J. Singerman, and J. M. Chokreff, "The detection and quantification of retinopathy using digital angiograms," IEEE Trans. Med. Imag., vol. 13, no. 4, pp. 619-626, Dec. 1994.
[17] O. Chutatape, L. Zheng, and S. M. Krishnan, "Retinal blood vessel detection and tracking by matched Gaussian and Kalman filters," in Proc. 20th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBS98), vol. 20, pp. 3144-3149, 1998.
[18] Y. A. Tolias and S. M. Panas, "A fuzzy vessel tracking algorithm for retinal images based on fuzzy clustering," IEEE Trans. Med. Imag., vol. 17, no. 2, pp. 263-273, Apr. 1998.
[19] A. Can, H. Shen, J. N. Turner, H. L. Tanenbaum, and B. Roysam, "Rapid automated tracing and feature extraction from retinal fundus images using direct exploratory algorithms," IEEE Trans. Inf. Technol. Biomed., vol. 3, no. 2, pp. 125-138, Jun. 1999.
[20] M. Lalonde, L. Gagnon, and M.-C. Boucher, "Non-recursive paired tracking for vessel extraction from retinal images," Vision Interface, pp. 61-68, 2000.
[21] J. Staal, M. D. Abramoff, M. Niemeijer, M. A. Viergever and B. van Ginneken, "Ridge-based vessel segmentation in color images of the retina," IEEE Trans. Med. Imag., vol. 23, no. 4, pp. 501-509, Apr. 2004.
[22] T. McInerney and D. Terzopoulos, "T-snakes: Topology adaptive snakes," Med. Image Anal., vol. 4, pp. 73-91, 2000.
[23] R. Toledo, X. Orriols, X. Binefa, P. Radeva, J. Vitri and J. Villanueva, "Tracking of elongated structures using statistical snakes," IEEE Comput. Soc. Conf. Comput. Vision Pattern Recog. (CVPR), 2000.
[24] A. Vasilevskiy and K. Siddiqi, "Flux maximizing geometric flows," IEEE Trans. Pattern Anal. Mach. Intell., vol. 24, no. 12, pp. 1565-1578, Dec. 2002.
[25] D. Nain, A. Yezzi, and G. Turk, "Vessel segmentation using a shape driven flow," Med. Image Comput. Comput.-Assist. Intervention MICCAI, 2004, pp. 51-59.
[26] S. Chaudhuri, S. Chatterjee, N. Katz, M. Nelson, and M. Goldbaum, "Detection of blood vessels in retinal images using two-dimensional matched filters," IEEE Trans. Med. Imag., pp. 263-269, 1989.
[27] A. Hoover, V. Kouznetsova and M. Goldbaum, "Locating blood vessels in retinal images by piecewise threshold probing of a matched filter response," IEEE Trans. Med. Imag., vol. 19, no. 3, pp. 203-211, Mar. 2000.
[28] A. Arnodo, N. Decoster and S. G. Roux, "A wavelet-based method for multifractal image analysis. I. Methodology and test applications on isotropic and anisotropic random rough surfaces," Eur. Phys. J. A, vol. 15, pp. 567-600, 2000.
[29] R. C. Gonzalez and R. E. Woods, Digital image processing, Prentice hall, second edition, 2002.
[30] J.P. Antoine, P. Carette, R. Murenzi, and B. Piette, "Image analysis with two-dimensional continuous wavelet transform," Signal Process., vol. 31, pp. 241-272, 1993.

[31] J. V. B. Soares, J. J. G. Leandro, R. M. Cesar, H. F. Jelinek and M. J. Cree, "Retinal vessel segmentation using the 2-D gabor wavelet and supervised classification." IEEE Trans. on Med. Imag., vol. 25, no. 9, pp. 1214-1222, September 2006.

[32] R. C. Gonzalez, R. E. Woods and S. L. Eddins, "Digital image processing using matlab," Prentice hall, second edition, 2007.

[33] Niemeijer and B. van Ginneken, 2002 [Online]. Available: http://www.isi.uu.nl/Reseach/Databases/DRIVE/results.php