A Novel Method for Vessel Detection Using Contourlet Transform

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Abstract— **Vessel detection is an important task for diagnosis of vascular diseases in clinical images. Many diseases such as diabetic retinopathy and hypertension can be detected by retinal vessel map or scanning conjunctival vessels. There are a lot of techniques for vessel extraction from retinal images but most of them have failed to face with some patterns like hemorrhages and micro aneurysms. In this paper we develop an algorithm based on Non-subsampled Contourlet Transform (NSCT) and morphological operations. By combining of information from two scales of contourlet and gray scale image, vessel map is extracted. Optic disc border is eliminated by Non-subsampled Contourlet directional information. In addition, circular shapes such as micro aneurysms are removed using morphological operations. We examine our algorithm on retinal images of DRIVE database and conjuntival images of Khatam database. Experimental results show significant improvements in achieving high accuracy and decreasing False Positive Rate (FPR) of vessel detection on both databases.**

Keywords-retinal vessels; conjunctival vessels; vessel detection; non-subsampled contourlet; morphological operation

I. INTRODUCTION

Automatic vessel detection and analysis can lead to early diagnosis of some diseases. For instance, diabetes is one of these disorders which can be detected even in primary stages using the study of vessel maps in different parts of body. Most of specialists are of the conception that eye vessels are more clear and distinguishable in comparison with those in the other parts of our body. Hence, a great number of works have been done on retinal vessel detection [1]-[14]. However, most of them could not to achieve acceptable accuracy and results.

Conjunctiva is a mucus membrane consisting of cells and underlying basement layer that covers the white part of the eye and lines inside of the eyelids. A few works have tried to detect conjunctival vessels [15]-[17] since vessels in conjunctival images are in low quality and contrast and it makes the vessel extraction process more difficult compared to those in retinal images. Moreover, similar to the retinal vessels, conjunctival vessels are in diverse sizes and shapes.

There have been many researches and papers on this area. We can categorize these methods to three general groups: tracking based algorithms, matched filters and multi resolution methods.

Eye vessels have several particular features that each method tries to use some of them to detect the vessel map. Tracking approaches are based on the assumption that vessels have tree structure and try to follow the vessel centerline or edges in gray level images [1]-[3]. These methods need to consider some initial seed points to begin the tracking using a growing approach to detect vessel pixels step by step.

Matched filter algorithms use this fact that Vessel profile can be approximated by Gaussian shape [4]-[6]. So, some predefined filters similar to cross section vessel profile are employed to detect vessels. These algorithms convolve these filters to the main image to extract the structures that are similar to the filters. As vessels have different widths and shapes, many filters are required to extract all vessels. Therefore, these methods are very time consuming.

In view of the fact that analysis of single scale information of an image cannot be so useful and practical in filtering and feature extraction areas, recently many studies and works have been done on multi resolution approaches to detect vessels[7]-[12]. These methods try to segment objects using different scales. High processing speed and resistance to noise are the main merits of multi resolution algorithms. These methods detect the main vessel structures in lower resolutions where as the small vessels can be extracted using high resolution information. Wavelet transform is one of the efficient tools for this purpose. In [8] an automatic retinal vessel detection method is presented. This method employs a classifier to group the pixels into two vessels and non-vessels classes based on the directional features that are extracted using multi resolution Gabor wavelet transform. Contourlet transform and curvelet transform are the other tools that are used in multi scale methods to detect vessels or enhance retinal images [13,14].

In this paper, NSCT is applied on retinal fundus and conjunctival images in different scales. Vessel map is extracted with combination of NSCT scales information and gray scale image. Furthermore, we use directional information obtained from NSCT to remove the border effect of optic disk. In addition, Morphological operations are employed for elimination of outliers such as micro aneurysms and hemorrhages.

Our algorithm is organized as follows. Proposed method is described in section II. Section III illustrates experimental results on retinal and conjunctival images. Finally, conclusion is presented in section IV.

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II. THE PROPOSED METHOD

Retinal and conjunctival vessels are linear dark objects with different width. Therefore, a filter with the constant scale cannot extract all vessels properly. Multi resolution approaches are one way to solve this problem. Wide vessels appear in coarser resolution scales and thinner ones can be extracted form finer resolution scales. Another merit of multi resolution methods is less computation time in comparison with other algorithms.

Among several multi resolution transforms, we employed NSCT for our algorithm because of its ability to capture geometric information of image and contour effectively. Moreover, it can achieve better frequently selectivity and regularity compared to contourlet.

To extract vessels from retinal image the border around optic disk and some outliers such as hemorrhages must be considered. But, on conjunctival images we do not face these problems. Our main algorithm has five major steps for extracting vessels from retinal images. These steps are modified for conjunctival images.

Five steps of our algorithm are as following:

- Pre-processing (retinal images)
- Non-subsampled contourlet transform
- Removing optic disk border (retinal images)
- Combination of NSCT scales information and gray scale image
- Elimination of vessel like patterns from retinal images (retinal image)

A. *Pre-processing*

Prior applying NSCT, we must remove the border around retinal image which appear because of camera's aperture. Therefore we use the same preprocessing methods as [8]. Interior neighboring pixels of border is expanded by morphological operation. As a result high contrast between fundus image and outside region is smoothed.

B. *Non-subsampled Contourlet Transform (NSCT)*

Non subsampled contourlet is a multi-scale and multi-directional transform which is proposed by Arthur L. da Cunha [19] in 2006. In contrary with contourlet transform, NSCT does not use down-sampling or up-sampling directional filter bank and pyramid structure, so this transform is shift invariant. NSCT decomposes image in several levels and different directions with the same size of original image. Therefore, each pixel in the original image corresponds to that of subbands in the same location.

To obtain contour information as dominant feature of vessels, NSCT is applied on our images in three scales and four orientations in each one. Small coefficient values in all subbands correspond to the noises and background, while big coefficient values in all subbands relate to strong vessels. Weak vessels have big coefficient values in some orientations and small coefficient values in other orientations. We use this information to obtain initial vessel maps form two coarser scales of NSCT as noises are appeared in finer scale.

The two initial Vessel maps are produced in two stages: first, computing the maximum response of all subbands in each scale. Second, applying threshold value on maximum response of each scale to remove most probable noise backgrounds. Threshold value is computed by one of the popular threshold methods, Otsu algorithm.

C. *Removing Optic Disk border on Retinal Images*

Retinal images include optic disk which is a rather round object and also brighter than the other parts of retina. As we can see in Fig. 1(b) some false vessels are detected in the vicinity of optic disk. Then, we utilize the brightness feature of optic disk and directional features of NSCT to remove border effects of this organ from the obtained vessel map of previous stage.

First, we find the approximated location of optic disk or bright part of retina by applying a threshold to the green channel of retinal image. Then, in the obtained area perpendicular edges to vessels are searched to find optic disk border. The edges which their directions are between 45 to 90 are removed form second and fourth quarters of optic disc area and false border with direction between 90 to 135 is eliminated from first and third quarters.

Fig. 1 depicts the vessel map in first scale of NSCT after removing optic disk borders.

D. *Combination of NSCT scales Information and gray scale Image*

In this stage we should join the obtained information from two scales of NSCT. A logical OR is performed to merge these two images so that main vessels and small vessels can be shown in one image. Result of merging process of two obtained images from the previous section is illustrated in Fig. 2.

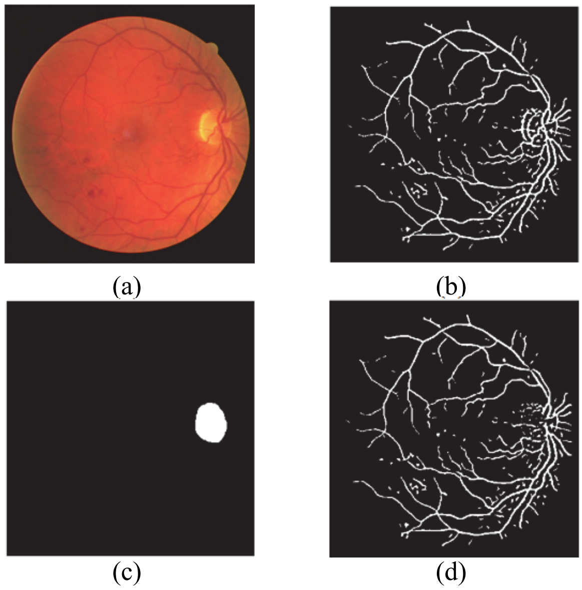


Figure 1. Vessel map after removing undesired effect of optic disk: a)RGB main Image, b)first scale of NSCT after thresholding in the second step, c)Approximated OD location and d)removing optic disk borders from (b)

However, there are some false detected vessels in Fig. 2 that should be eliminated. It is evident that vessels in the main gray level image are darker than the background and have small gray levels. Then, we use the gray level property of vessels to omit undesired objects from our result. The vessel map image is scanned locally with a window of 3×3 pixels to decide whether we remove the pixels under the window from the vessel map or not. If the average gray level of vessel pixels in the processed window corresponding to the main gray scale image is lower than a specified threshold T, we omit the all 9 pixels under the window from the extracted vessels.

E. Elimination of Vessel Like Patterns

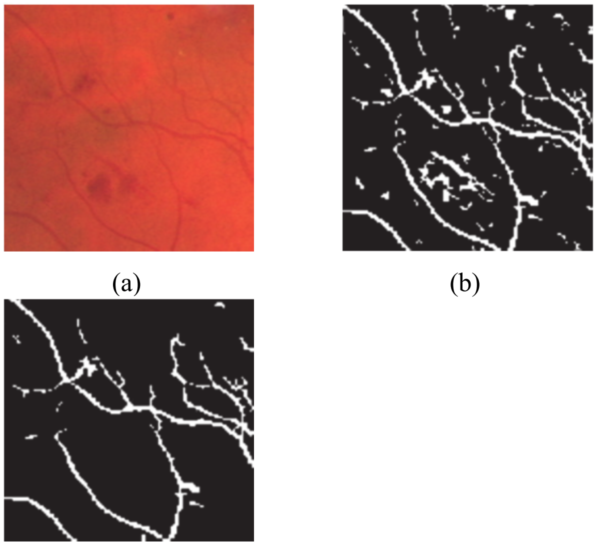
So far we combined the information of NSCT scales and gray scale image to attain the vessel map. Similar to most of the vessel detection methods, there are some outliers in the result. These outliers include some vessel like patterns such as micro aneurisms and hemorrhages that can be seen in retinal images. In this section we employ a simple algorithm to remove these regions so that improve the accuracy and decrease the false positive rate of our vessel detection approach.

Considering the features of micro aneurisms and hemorrhages in retinal images which are rather circular regions with gray levels of similar to the vessels we try to remove them. Usually most of noises are also small round regions that can be removed using length filter. Therefore, we utilize morphological operations to reach our goal. First, we compute the major axis length and minor axis length of each region in the obtained vessel map image to detect the circular objects. Since the vessels are linear objects in retinal image, we can remove the regions with almost equal major and minor axis length. At last, we omit the regions which are smaller than a specified area A to detect the noises which are labeled as vessels in the previous stages.

Fig. 3 shows the enhanced vessel map of a sub image after removing vessel like patterns.

It can be seen from the figure that most of outliers like noises, micro aneurisms and hemorrhages are eliminated after applying the presented algorithm of this step.

Figure 2. Result of merging the first two scales of NSCT after removing OD borders effect from each two scales

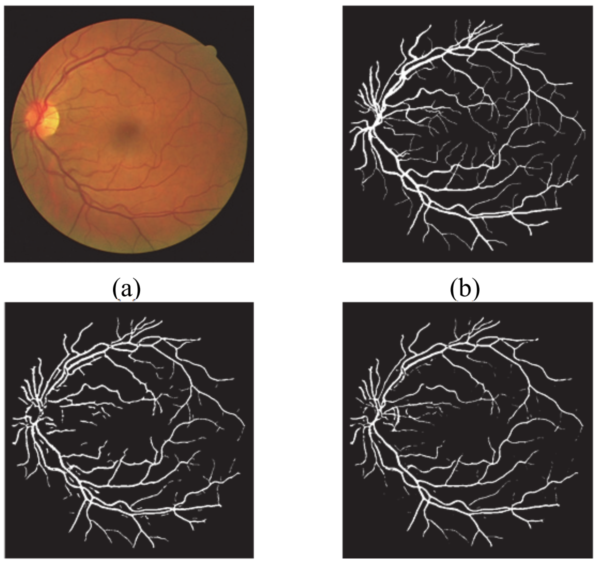


(a) (b) (c)

Figure 3. Enhanced vessel map after removing outliers: a)main image, b)exteracted vessels before removing outliers and b)exteracted vessels after removing outliers

III. EXPERIMENTAL RESULTS

In the first experiment we applied our vessel detection method on 40 retinal images of DRIVE database [18]. To evaluate the performance of our proposed algorithm objectively we use accuracy rate which is the fraction of correctly labeled pixels as vessel or background. Fig. 4 shows a sample of segmented retinal image using the proposed algorithm in this paper. Moreover, result of another popular vessel detection method [8] on the same image is illustrated in this figure.



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

Figure 4. Vessel detection results: a)main image b) manual segmentation, c)our method and d)proposed method in [8].

According to the above figure it is clear that the proposed methods in [8] like the most other works in this area does not remove the border effects of optic disk whereas our method can detect and omit the undesired effect efficiently and decrease the false positive rate of detected vessels in the vicinity of optic disk.

In our algorithm the parameters T and A are set to 100 and 10 respectively.

Table I compares our algorithm to some other well-known vessel extraction methods on DRIVE database according to average accuracy rate of vessel detection on all images.

Our algorithm outperforms the methods [8,5,20] whereas the supervised algorithm [8] has a little higher accuracy compared to our method. However, in addition to less time complexity as our algorithm is unsupervised, false positive rate is lower than [8]. Average false positive value of the proposed algorithm for 20 test images of DRIVE database is 0.017 whereas this value is 0.282 in [8].

To evaluate the performance of our vessel detection algorithm on conjunctival images, we used Khatam database[1]. This database contains 20 conjunctival images along with their manually extracted vessels which are provided by an ophthalmologist. The images are in RGB format with 461×469 pixels and 8 bits per color channel. These images are captured by Canon EOS 350D DIGITAL camera.

To extract vessels of conjunctival images, we first apply NSCT on the image and then information of two NSCT scales are combined with gray scale image. As mentioned above, the other three steps are not necessary since there are no camera's aperture problem and optic disk in these images.

We compared our algorithm with Reza Pourreza et al. [15] and supervised NSCT algorithm [14]. Fig. 5 shows the result of our work and the two other methods on a sample conjunctival image. Features vector of each pixel in supervised NSCT method is obtained by maximum response of two scales along with gray value of that pixel. We divided our images in two sets of training and test groups. Then, Gaussian Mixture Model (GMM) classifier is employed to classify pixels to vessels and non-vessels.

As you can see from Fig.5 (c) Pourreza et.al method which based on Radon transform cannot detect vessel border smoothly as well as extracting some false contour around non vessel object. In conjunctival images, thin vessels have very low contrast; therefore supervised NSCT algorithm cannot distinguish thin vessels from background. Fig.5 (d) shows that NSCT algorithm based on training tends to classify thin vessels as background.

TABLE I. RESULTS OF OUR PROPOSED ALGORITHM AND SOME OTHER VESSEL DETECTION METHODS.

Vessel detection method	Accuracy
Our proposed method	0.9381
Soares et al.[8]	0.9466
Chaudhuri et al.[5]	0.8850
Li and Chutatape[20]	0.8939

[1] Images of this database are gathered by Khatam-Al-Anbia eye hospital, Mashhad, Iran.

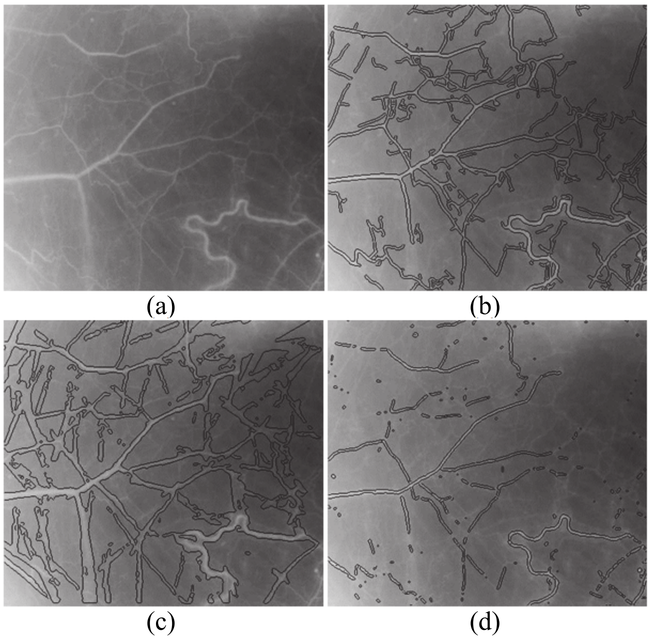


Figure 5. Result of vessel segmenation by three different methods. (a) An example of conjunctival image.(b) result of our algorithm. (c) vessel segmenation by[15].(d) vessel segmenation by supervised NSCT algorithm

IV. CONCLUSION

We have proposed a novel algorithm based on Non subsampled contourlet transform. Maximum response of two NSCT scales with gray scale value is combined for vessel segmentation form both conjunctival and retinal images. We use directional information of NSCT to distinguish between optic disc border with retinal vessels which is most common misclassified region among other literature.

We have showed that, our algorithm avoid to detect of some vessel like pattern with help of morphological operation as well as achieve better performance in compare with other algorithm in both conjunctival and retinal image. In addition, simplicity and low time complexity are the other advantages of the proposed vessel extraction method which the most presented methods in this application lack.

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REFERENCES

[1] A. Osareh and B. Shadgar, "An Automated Tracking Approach for Extraction of Retinal Vasculature in Fundus Images," journal of ophthalmic and vision research, vol. 5, 2010.

[2] Lecornu, L., C. Roux, and J. Jacque, "Extraction of Vessel Contours in Angiograms by Simultaneous Tracking of the Two Edges", IEEE Conf. Eng. in Medicine and Bio., Vol. 1, pp. 678-679, 1994.

[3] T. Yedidya and R. Hartley, "Tracking of Blood Vessels in Retinal Images Using Kalman Filter," in Computing: Techniques and Applications, 2008. DICTA '08.Digital Image, pp. 52-58, 2008.

[4] A. D. Hoover, V. Kouznetsova, and M. Goldbaum, "Locating blood vessels in retinal images by piecewise threshold probing of a matched

filter response," IEEE Transactions on Medical Imaging, vol. 19, pp. 203-210, 2000.

[5] S. Chaudhuri, S. Chatterjee, N. Katz, M. Nelson, and M. Goldbaum, "Detection of blood vessels in retinal images using two-dimensional matched filters," *IEEE Transactions on Medical Imaging,* vol. 8, pp. 263-269, 1989.

[6] A. Banumathi, R. K. Devi, Raju, and V. A. Kumar, "Performance analysis of matched filter techniques for automated detection of blood vessels in retinal images," in TENCON 2003. Conference on Convergent Technologies for Asia-Pacific Region, Vol. 2, pp. 543-546, 2003

[7] M. Palomera-Perez, E. Martinez, H. Benitez-Perez, and J. Ortega-Arjona, "Parallel Multi-scale Feature Extraction and Region Growing: Application in Retinal Blood Vessel," IEEE Transactions on Information Technology in Biomedicine, 2009.

[8] J. V. B. Soares, J. J. G. Leandro, R. M. Cesar, H. F. Jelinek, and M. J. Cree, "Retinal vessel segmentation using the 2D Gabor wavelet and supervise classification," IEEE Transactions on Medical *Imaging*, vol. 25, no. 9, pp. 1214–1222, 2006.

[9] R. Ghaderi, H. Hassanpour, and M. Shahiri, "Retinal vessel segmentation using the 2-D Morlet wavelet and neural network," International Conference on Intelligent and Advanced Systems, ICIAS, pp. 1251-1255, 2007.

[10] D. J. Cornforth, H. J. Jelinek, J. J. G. Leandro, J. V. B. Soares, R. M. Cesar, Jr., M. J.Cree, P. Mitchell, and T. Bossomaier, "Development of retinal blood vessel segmentation methodology using wavelet transforms for assessment of diabetic retinopathy," in Complexity International, 2005.

[11] J. J. G. Leandro, J. V. B. Soares, R. M. Cesar, Jr., and H. F. Jelinek, "Blood vessels segmentation in nonmydriatic images using wavelets and statistical classifiers," XVI Brazilian Symposium on Computer Graphics and Image Processing, pp. 262-269, 2003.

[12] L. Qin, J. You, Z. Lei, D. Zhang, and P. Bhattacharya, "A New Approach to Automated Retinal Vessel Segmentation Using Multiscale Analysis," 2006. ICPR 2006. 18th International Conference on Pattern Recognition, pp. 77-80, 2006.

[13] Miri, M.S.; Mahloojifar, A.; , "Retinal Image Analysis Using Curvelet Transform and Multistructure Elements Morphology by Reconstruction,"IEEE Transactions on Biomedical Engineering, vol.58, no.5, pp.1183-1192, 2011.

[14] Zhong Hua, Jiao Li.Cheng HOU Peng ,"retinal vessel segmentation using nonsubsampled Contourlet Transform", Chinese Journal of Computers, No.3, pp.574-582, 2011.

[15] R. Pourreza, T. Banaee, H. Pourreza, and R.D. Kakhki, "A Radon Transform Based Approach for Extraction of Blood Vessels in Conjunctival Images," Springer, pp. 948 – 956, 2008.

[16] C.G. Owen, R. S.B. Newsom, A.R. Rudnicka, T.J. Ellis, and E.G. Woodward, "Vascular Response of the Bulbar Conjunctiva to Diabetes and Elevated Blood Pressure," Ophthalmology, vol. 112, pp. 1801-1808, 2005.

[17] R. Derakhshani, A. Ross, and S. Crihalmeanu, "a new biometric modality based on conjunctival vasculature," in Artificial Neural Networks in Engineering (ANNIE), St. Louis, USA, 2006.

[18] M. Niemeijer, B. vanGinneken, 2002 [Online]. Available: http://www.isi.uu.nl/Reseach/Databases/DRIVE/results.php.

[19] A. L. Cunha, J. Zhou, and M. N. Do, "The nonsubsampled contourlet transform: theory, design and applications," IEEE Trans. Image Proc., submitted, 2005

[20] H. Li, O. Chutatape, "Fundus image feature extraction", Proceeding of the 22nd IEEE Conference on Engineering in Medicine and Biology Society, vol. 1, pp. 3071–3073, 2000.