journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Improvement of retinal blood vessel detection using morphological component analysis

Elaheh Imani[*,1], *Malihe Javidi*[2], *Hamid-Reza Pourreza*[1,3]

Machine Vision Lab., Ferdowsi University of Mashhad, Mashhad, Iran

A R T I C L E I N F O

Article history:
Received 27 July 2014
Received in revised form
22 January 2015
Accepted 26 January 2015

Keywords:
Retinal blood vessel
Diabetic retinopathy
Morphological component analysis (MCA)
Morlet Wavelet Transform
Adaptive thresholding

A B S T R A C T

Detection and quantitative measurement of variations in the retinal blood vessels can help diagnose several diseases including diabetic retinopathy. Intrinsic characteristics of abnormal retinal images make blood vessel detection difficult. The major problem with traditional vessel segmentation algorithms is producing false positive vessels in the presence of diabetic retinopathy lesions. To overcome this problem, a novel scheme for extracting retinal blood vessels based on morphological component analysis (MCA) algorithm is presented in this paper. MCA was developed based on sparse representation of signals. This algorithm assumes that each signal is a linear combination of several morphologically distinct components. In the proposed method, the MCA algorithm with appropriate transforms is adopted to separate vessels and lesions from each other. Afterwards, the Morlet Wavelet Transform is applied to enhance the retinal vessels. The final vessel map is obtained by adaptive thresholding. The performance of the proposed method is measured on the publicly available DRIVE and STARE datasets and compared with several state-of-the-art methods. An accuracy of 0.9523 and 0.9590 has been respectively achieved on the DRIVE and STARE datasets, which are not only greater than most methods, but are also superior to the second human observer's performance. The results show that the proposed method can achieve improved detection in abnormal retinal images and decrease false positive vessels in pathological regions compared to other methods. Also, the robustness of the method in the presence of noise is shown via experimental result.

1. Introduction

Retinal vessel segmentation and quantitative measurement of vessel variations is crucial in many research efforts related to vascular features. Analysis of vascular structures could be used to diagnose several diseases such as diabetic retinopathy, glaucoma and hypertension. In many clinical investigations, segmentation of retinal blood vessel becomes a prerequisite for the analysis of vessel parameters such as tortuosity and vessel width. Manual segmentation of blood vessels is a time consuming task that requires remarkable skills. Therefore, the development of algorithms for automatic vessel segmentation and vessel diameter estimation is of paramount importance.

* *Corresponding author*. Tel.: +98 9372883910.
E-mail addresses: elaheh.imani@gmail.com (E. Imani), ma.javidi.1984@stu.um.ac.ir (M. Javidi), hpourreza@um.ac.ir (H.-R. Pourreza).
[1] Member of Eye Image Analysis Research Group (EIARG).
[2] Tel.: +98 9155228801.
[3] Tel.: +98 9374346472.

http://dx.doi.org/10.1016/j.cmpb.2015.01.004

It is commonly acknowledged in the medical community that the first stage in the development of a computer-assisted diagnostic system is the automatic quantification of retinal vessels [1].

Retinal vessel segmentation is still a challenging issue that has been widely studied in the literature. These studies can be classified into six categories: (1) matched filtering, (2) multi-scale algorithms, (3) pattern recognition methods, (4) vessel tracking, (5) model-based techniques and (6) mathematical morphology [1].

In matched filtering methods, retinal images are filtered by various vessel-like kernels which are designed to model a specific feature in the image at different positions and orientations. The presence of the desired feature is recognized using the matched filter response [1]. Jiang and Mojon [2] proposed a method based on a verification-based multi-threshold probing scheme. In this method, the image was probed with different thresholds and a vessel map was obtained by combining images derived from probed thresholds followed by post-processing algorithms. The method was evaluated on the DRIVE dataset, reporting an average accuracy of 0.92 and an area of 0.94 under the ROC curve. In [3] a 2D Gaussian matched filter was used to enhance the retinal images and simplified pulse coupled neural network (PCNN) was employed to segment the blood vessels by firing neighborhood neurons. Then, a 2D Otsu thresholding was used to search for the best segmentation results. The final vessel map was obtained through the analysis of regional connectivity. The evaluation of the methodology yielded a true positive rate of 0.80 and a false positive rate of 0.02 on the STARE dataset. Bankhead et al. [4] proposed a method based on Wavelet Transform. The methodology achieved a sensitivity of 0.7027 and specificity of 0.9717 on the DRIVE dataset. A method based on Gabor Wavelet and multilayered thresholding was proposed in [5]. The evaluation of the method on the DRIVE and STARE datasets achieved an average accuracy of 0.9502. The objective of the multi-scale approaches is to detect vessels with varying widths. Vlachos and Dermatas [6] proposed a multi-scale line tracking vessel detection method, which started from seed points derived from a brightness selection rule from a normalized histogram, and terminated when a cross-sectional profile condition became invalid. The multi-scale confidence image map was achieved by combining the multi-scale line tracking results. The final vessel network was derived from the quantization map of the multi-scale confidence matrix followed by a post-processing step which removed erroneous artifacts. The method attained an average accuracy of 0.92, a sensitivity of 0.74 and a specificity of 0.95. A vessel detection method based on line detection was proposed in [7]. This algorithm is based on the fact that changing the length of a basic line detector produces line detectors with varying scales. The final vessel map was obtained by combining line responses at varying scales. The method was evaluated on the DRIVE and STARE datasets, yielding an average accuracy of 0.9407 and 0.9324, respectively.

Pattern recognition methods are divided into two subclasses: supervised and unsupervised methods. Supervised methods use some prior information to create the vessel map, while detection of vessels in the unsupervised methods is performed without any prior labeling information. Niemeijer et al. [8] created a feature vector comprising of the green channel of the image and the responses of Gaussian matched filter. Then, the K-Nearest Neighbor (KNN) algorithm was used to estimate the probability map. Finally, the retinal vessel map was created by thresholding the probability map. Staal et al. [9] introduced an algorithm based on the extraction of image ridges, which coincided approximately with vessel centerlines. With line elements, the image was partitioned into patches by assigning each image pixel to the closest line element. A feature vector was created for each pixel using the patch properties and the line elements as inputs to the KNN classifier. In [10] a method based on radial projection and semi-supervised self-training was proposed for vessel segmentation using SVM. The vessel centerlines were located using radial projection and the major structure of vessels was extracted by applying a semi-supervised self-training classifier. The average accuracy, sensitivity and specificity were 0.94, 0.74 and 0.97, for DRIVE dataset and 0.94, 0.72 and 0.97 for STARE dataset, respectively. Kande et al. [11] proposed an unsupervised fuzzy-based vessel segmentation algorithm. In this method, first the contrast of retinal images was enhanced by a matched filter, and then a weighted fuzzy C-means clustering algorithm was used to identify the vascular tree structures. The combination of 2-D Gabor Wavelet and supervised classification was employed by Soares et al. [12] for retinal vessel segmentation. A feature vector comprising of pixel intensity and Gabor Wavelet Transform responses at multiple scales was used as inputs for a Gaussian mixture model classifier to classify each pixel as either a vessel or non-vessel pixel. The method achieved an average accuracy of 0.9466 and 0.9480 on the DRIVE and STARE datasets, respectively. A method based on neural networks was proposed in [13], which used a 7-d feature vector composed of moment invariant and gray level features. Finally a neural network was employed for the purpose of training and classification. The method was evaluated on the DRIVE and STARE datasets, yielding an accuracy of 0.9452 and 0.9526, respectively. Ricci and Perfetti [14] introduced a method based on line operators and SVM classifier for pixel classification. The line operator was based on the evaluation of the average gray level along lines of fixed length that passed through the target pixel at different directions. The evaluation of the method yielded an average accuracy of 0.9563 and 0.9584 on the DRIVE and STARE datasets, respectively.

The vessel tracking methods segment vessel map between two points based on local information. An automatic model-based algorithm for vessel segmentation was proposed in [15]. The algorithm utilized a parametric model of a vessel which exploited geometric properties for parameter definitions.

In model-based approaches, the retinal vessel map was extracted by applying the explicit vessel models. Diri et al. [16] proposed a method for retinal vessel segmentation using a Ribbon of Twins active contour model. This method used two pairs of contours to capture each vessel edge, while maintaining the width consistency. The method proposed by Lam et al. [17] was based on regularization-based multi-concavity modeling. The method was evaluated on the DRIVE and STARE datasets, yielding an accuracy of 0.9472 and 0.9567, respectively. Espona et al. [18] proposed a vessel segmentation method based on classical snake in combination with blood