BIOCYBERNETICS AND BIOMEDICAL ENGINEERING 36 (2016) 119–129

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/bbe

Original Research Article

New Binary Hausdorff Symmetry measure based seeded region growing for retinal vessel segmentation

Rashmi Panda *, *N.B. Puhan*, *Ganapati Panda*

School of Electrical Sciences, Indian Institute of Technology Bhubaneswar, India

ARTICLE INFO

Article history:
Received 13 July 2015
Received in revised form
23 September 2015
Accepted 1 October 2015
Available online 26 October 2015

Keywords:
Vessel segmentation
Glaucoma
Diabetic retinopathy
Seeded region growing
Symmetry
Hausdorff distance

ABSTRACT

Automated retinal vessel segmentation plays an important role in computer-aided diagnosis of serious diseases such as glaucoma and diabetic retinopathy. This paper contributes, (1) new Binary Hausdorff Symmetry (BHS) measure based automatic seed selection, and (2) new edge distance seeded region growing (EDSRG) algorithm for retinal vessel segmentation. The proposed BHS measure directly provides a binary symmetry decision at each pixel without the computation of continuous symmetry map and image thresholding. In a multiscale mask, the BHS measure is computed using the distance sets of opposite direction angle bins with sub-pixel resolution. The computation of the BHS measure from the Hausdorff distance sets involves point set matching based geometrical interpretation of symmetry. Then, we design a new edge distance seeded region growing (EDSRG) algorithm with the acquired seeds. The performance evaluation in terms of sensitivity, specificity and accuracy is done on the publicly available DRIVE, STARE and HRF databases. The proposed method is found to achieve state-of-the-art vessel segmentation accuracy in three retinal databases; DRIVE-sensitivity (0.7337), specificity (0.9752), accuracy (0.9539); STARE-sensitivity (0.8403), specificity (0.9547), accuracy (0.9424); and HRF-sensitivity (0.8159), specificity (0.9525), accuracy (0.9420).

1. Introduction

Retinal blood vessel morphology such as vessel diameter, branching, tortuosity, neovascularization, arteriovenous nicking provides important and valuable information about many serious disorders of eye and other physiological processes [1]. Image processing based removal of blood vessels in optic disc region enables better assessment of glaucoma [2]. Neovascularization is a sign of diabetic retinopathy [3]. Changes in vessel branching and tortuosity are symptoms of hypertensive retinopathy [4,5]. The presence of arteriovenous nicking is an important indicator of stroke [6]. Hence, the diagnostic information regarding these diseases is linked to accurate extraction of retinal blood vessels.

* *Corresponding author at*: School of Electrical Sciences, Indian Institute of Technology Bhubaneswar, India.
E-mail addresses: rp14@iitbbs.ac.in (R. Panda), nbpuhan@iitbbs.ac.in (N.B. Puhan), gpanda@iitbbs.ac.in (G. Panda).
http://dx.doi.org/10.1016/j.bbe.2015.10.005

When a large number of patients undergo regular screening, computer-aided diagnosis provides more effective solution instead of using only manual measurements. Further, automatic segmentation and analysis of retinal vasculature can improve reliability and reproducibility of decision making. Automated retinal vessel segmentation encounters several challenges: complex nonlinear structure of blood vessels, wide range of widths (scale), variable low contrast between blood vessels and background, various structures like optic disc, fovea and exudates interrupt the vessel segmentation process.

In literature, the supervised segmentation methods utilize ground truth images for the classification of vessels based on a given set of features. Niemeijer et al. [7] and Staal et al. [8] applied k-nearest neighbor (KNN) algorithm to estimate the probability of the pixel belonging to a vessel. Soares et al. [9] used a Bayesian classifier with class-conditional probability density functions (likelihoods) described as Gaussian mixtures. The feature vector is composed of pixel's intensity and response of the Gabor wavelet transform. Lupascu et al. introduced feature-based AdaBoost classifier for retinal blood vessel segmentation [10]. Ricci and Perfetti [11] employed line operators and support vector machine based classification. A five-layer feed-forward neural network is used by Marin et al. [12] and the feature vector is computed by combination of moment-invariant and gray-level features. Gardner et al. [13] proposed a back propagation multilayer neural network (NN) for vascular tree segmentation. The NN was fed with the values of the pixel in a 20×20 window at each pixel after histogram equalization, smoothing and edge detection.

The unsupervised methods work without any prior labeling knowledge. The concept of matched filter for retinal blood vessel extraction was proposed by Chaudhuri et al. [14]. The authors explored cross-sectional Gaussian intensity profile of blood vessel. Hoover et al. [15] and Gang et al. [16] further exploited this approach using a threshold probing technique to test whether the local piece is a vessel or not. Zhang et al. [17] used zero mean Gaussian filter and first order derivative of Gaussian (FODG) to detect the blood vessel.

Zana et al. [18] applied morphological filters in combination with cross-curvature evaluation to segment vessel-like patterns in retinal images. Mendonca et al. [19] used the Difference of Offset Gaussian (DoOG) filter to detect the centerline and then applied multiscale morphological reconstruction with iterative region growing to segment the blood vessel. Fraz et al. [20] detected the centerline and subsequently applied multidirectional morphological top-hat operator with a linear structuring element followed by bit plane slicing to detect the blood vessel. Odstrcilik et al. proposed a matched filtering based method in a newly created High Resolution Fundus (HRF) retinal database [21].

Chutatape et al. [22] used second order Gaussian matched filter to find the centerline points and then used Kalman filters and branch detection method for tracking blood vessels in retinal images. Can et al. [23] proposed a real time vessel tracking algorithm using directional templates around each candidate vessel point. Condurache et al. described a paradigm of hysteresis-classifier for vessel segmentation with multidimensional feature vector [24].

Frangi et al. [25] examined the multiscale second order (Hessian) local structure of MRA (angiogram) image in the context of developing a vessel enhancement filter. The vesselness measure is obtained on the basis of eigenvalue analysis of the Hessian matrix. Similar approach has been applied for retinal blood vessel segmentation by Martinez et al. in [27]. They applied first and second derivative (edge and maximal principal curvature) in multiple scales. In [28], a vesselness likelihood ratio is used for vessel centerline extraction that combines multiscale matched filter response, confidence measures and vessel boundary measures. In [29], multiscale line operator is investigated for segmentation of retinal blood vessel. Espona et al. [30] used the classical snake in combination with blood vessel topological properties to extract the vasculature from retinal images. Mahadevan et al. [31] used a variety of vessel profile models including Gaussian, derivatives of Gaussian and dual Gaussian and various noise models like Gaussian and Poisson noise. The gradient vector flow approach has been applied for retinal blood vessel segmentation by Tang et al. in [32]. A detailed survey on retinal blood vessel segmentation can be found in the paper by Kirbas et al. [33] and Fraz et al. [34].

In this paper, we follow a seeded region growing approach for accurate retinal vessel segmentation. The seeded region growing process starts from a set of selected seeds and grows into its neighbors being guided by regional features [35]. Automatic seed selection thus plays a critical role in seeded region growing based segmentation. In this paper, our contribution is twofold. First, we explore the symmetry property inherent in the blood vessel geometry to design a new Binary Hausdorff Symmetry (BHS) measure. The BHS measure enables accurate seed (centerline) selection in retinal blood vessels. Unlike the existing symmetry measure, the BHS measure does not require any continuous symmetry map and image thresholding computation. Secondly, the selected seed pixels are applied into the newly designed edge distance region growing (EDSRG) algorithm for vessel segmentation.

The rest of the paper is organized as follows: In Section 2, we present the new Binary Hausdorff Symmetry (BHS) measure followed by edge distance seeded region growing algorithm. Section 3 describes three publicly available retinal image databases along with the performance measures. The section also contains the results and comparison with existing methods. Finally, Section 4 concludes the paper.

2. Proposed vessel segmentation method

In this section, we propose a new Binary Hausdorff Symmetry (BHS) measure for automatic seed selection along with the EDSRG algorithm. The proposed vessel segmentation method can be divided into four parts; (1) image preprocessing, (2) identification of seed (centerline) pixels using the BHS measure, (3) postprocessing to remove false centerline pixels, (4) vessel segmentation using the new edge distance seeded region growing (EDSRG). A preliminary version of the proposed method can be found in [36]. Fig. 1(a) is considered as a test image for demonstration of the proposed method.