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Original Research Article

Retinal blood vessel segmentation employing image processing and data mining techniques for computerized retinal image analysis

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ABSTRACT

Most of the retinal diseases namely retinopathy, occlusion etc., can be identified through changes exhibited in retinal vasculature of fundus images. Thus, segmentation of retinal blood vessels aids in detecting the alterations and hence the disease. Manual segmentation of vessels requires expertise. It is a very tedious and time consuming task as vessels are only a few pixels wide and extend almost throughout entire span of the fundus image. Employing computational approaches for this purpose would help in efficient retinal analysis. The methodology proposed in this work involves sequential application of image pre-processing, supervised and unsupervised learning and image post-processing techniques. Image cropping, color transformation and color channel extraction, contrast enhancement, Gabor filtering and halfwave rectification are sequentially applied during pre-processing stage. A feature vector is formed from the pre-processed images. Principal component analysis is performed on the feature vector. *K*-means clustering is executed on this outcome to group pixels as either vessel or non-vessel cluster. Out of the two groups, the identified non-vessel group undergoes an ensemble classification process employing root guided decision tree with bagging, while vessel group is left unprocessed as further processing might increase misclassifications of vessels as non-vessels. The resultant segmented image is formed through combining the results of clustering and ensemble classification process. The vessel segmented output from previous phase is post-processed through morphological techniques. The proposed technique is validated on images from publicly available DRIVE database. The proposed methodology achieves an accuracy of 95.36%, which is comparable with the existing blood vessel segmentation techniques.

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1. Introduction

Fundus imaging [1] provides a valuable resource for analysis of the retina. The fundus image of the retina discloses anatomical structures [2] such as retinal vasculature, optic disk, macula and abnormal structures such as microaneurysms, hemorrhages, exudates, cottonwool spots etc., if present. Optic disk (exposed as a bright oval structure) represents the start of the optic nerve head and is the entry point for major blood vessels to the eye. Macula (observed as a dark region devoid of vessels) with the fovea at its center is responsible for central and high resolution vision. The blood vasculature is a tree like structure spanning across the fundus image. It is a high frequency component exhibited more clearly at high contrast. The retinal blood vessels are one of the most important structures of the retina providing blood supply to the retina and also transmitting the information signals from the retina to the brain [3].

The changes in retinal blood vessels serve as a bio-marker for identification of many disorders such as diabetic retinopathy, hypertensive retinopathy, retinal artery occlusion, retinal vein occlusion, etc. Not only retinal diseases, but also diseases such as stroke, hypertension and diabetes produce noticeable alterations in the retinal blood vasculature. Most of the retinal disorders that cause modifications in the vascular network would lead to vision loss. Diagnosing these disorders, at the initial stage can prevent the vision loss to a greater extent. Changes in the vascular network pertain to its shape, width, tortorisity, branching pattern etc. Hence segmentation of blood vessels in the fundus image and further analysis of its properties aids in diagnosis of retinal vascular disorders. Also, segmentation of blood vessels and hence extraction of vascular points is useful for image registration [3]. Even for people with expertise, segmentation of blood vessels is a time consuming and effort prone process. Utilization of the power of computational intelligence to automatically segment the blood vessels in fundus images would be highly appreciated by the ophthalmologists. Various such techniques have been adopted in the literature to segment the retinal vessels. However, automatic segmentation of retinal blood vessels is also challenging due to the various complications pertaining to its structure and influence from other sources. The difficulties arise due to variations in vessel appearance, shape and orientations; low contrast between the blood vessels and its background; disturbances caused to the presence of noise and the existence of abnormal structures such as lesions, exudates, microaneurysms and other diseased regions. These complications might mislead an automatic vessel segmentation algorithm by misinterpreting background to vessels and overlooking or missing the thin vessels.

In this research, a blood vessel segmentation approach for segmenting the blood vessels in fundus images is presented. This approach attempts to segment the vessels through chronological application of image pre-processing (image cropping, color transformation and color extraction, Gabor filtering, halfwave rectification), supervised and unsupervised learning (principal component analysis, clustering and classification) and image post-processing techniques. The review of the state-of-art techniques in retinal blood vessel segmentation, the dataset used for validation, the methodology proposed, experimental results of the work and the conclusions are presented in detail in the further sections.

2. Review of the related studies

Retinal blood vessel segmentation is achieved through assigning each pixel as either a vessel pixel or non-vessel pixel. The retinal vessel segmentation methodologies can be seen in different dimensions. In a broad sense, the vessel segmentation methodologies can be divided into two categories namely rule based techniques and pattern recognition based techniques. Vessel tracking, matched filtering, mathematical morphology, multi-scale techniques and model based approaches fall under the rule based category [4]. Alternatively, supervised techniques involving building classification models for categorization of the pixels and clustering models for grouping of pixels as either vessel or non-vessel pixels are included under the pattern recognition based techniques. The supervised methodologies require data of manually labeled vessel and non-vessel pixels for the purpose of training the model which is used for classification.

Regarding the pattern recognition based methodologies; generally there exist two stages where during the first stage, image is enhanced and required features are extracted followed by the second stage which classifies each pixel as either a vessel or non-vessel. A few attempts to classify the pixels were made through the supervised techniques which are concisely highlighted here. These methods differ in the feature vector and classification process adopted. Since blood vessels are elongated structures in the fundus image, Staal et al. [5] utilized the concept of ridges for vessel extraction. The properties of the ridges and the pixel considered forms the feature vector. *K*-nearest neighbor (KNN) classification procedure, which gave better results than a linear and quadratic classifier was adopted for classifying the image ridges achieving an accuracy of 94.41% with a computational time of 900 s using 1 GHz processor. Subsequently, Niemeijer et al. [6] attempted KNN classification on a 31D feature vector which included the intensity of green channel and responses of Gaussian and its derivative at various scales resulting in an accuracy of 94.16%. Then, Soares et al. [7] utilized Bayesian classifier with Gaussian mixture models for fast classification on a feature vector comprising of Gabor wavelet responses at various scales, providing an accuracy of 94.66%. This methodology used one million pixels for training and consumed 9 h for training and 30 s for classification. In another attempt, Marin et al. [8] demonstrated a neural network based classifier (nonlinear classification procedure) on a 7D feature vector formed from the gray level and the moment invariant features achieving an accuracy of 94.52%. This method processes an image in less than 90 s due to its simplicity of operation. Again, Franklin et al. [3] made an attempt using neural networks to segment retinal vessels, through a feature vector formed using the intensities of red, green and blue channels of the RGB image yielding an accuracy of 95.03%.

Strategies were introduced to deal with large and small vessels separately. Xu et al. [9] adopted Adaptive local thresholding to extract large vessels and support vector