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# Automated characterization of blood vessels as arteries and veins in retinal images

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ABSTRACT

In recent years researchers have found that alternations in arterial or venular tree of the retinal vasculature are associated with several public health problems such as diabetic retinopathy which is also the leading cause of blindness in the world. A prerequisite for automated assessment of subtle changes in arteries and veins, is to accurately separate those vessels from each other. This is a difficult task due to high similarity between arteries and veins in addition to variation of color and non-uniform illumination inter and intra retinal images. In this paper a novel structural and automated method is presented for artery/vein classification of blood vessels in retinal images. The proposed method consists of three main steps. In the first step, several image enhancement techniques are employed to improve the images. Then a specific feature extraction process is applied to separate major arteries from veins. Indeed, vessels are divided to smaller segments and feature extraction and vessel classification are applied to each small vessel segment instead of each vessel point. Finally, a post processing step is added to improve the results obtained from the previous step using structural characteristics of the retinal vascular network. In the last stage, vessel features at intersection and bifurcation points are processed for detection of arterial and venular sub trees. Ultimately vessel labels are revised by publishing the dominant label through each identified connected tree of arteries or veins. Evaluation of the proposed approach against two different datasets of retinal images including DRIVE database demonstrates the good performance and robustness of the method. The proposed method may be used for determination of arteriolar to venular diameter ratio in retinal images. Also the proposed method potentially allows for further investigation of labels of thinner arteries and veins which might be found by tracing them back to the major vessels.



## 1. Introduction

Retinal image analysis has been an active field of research in the scope of medical image processing for years since it has been realized that alternations in retinal vascular network are associated with several cardiovascular disorders. Recently, ophthalmologists have assigned the small changes in the caliber of arteries and veins to several micro-vascular diseases such as diabetic retinopathy. Diabetic retinopathy is an increasingly growing public health problem and the leading cause of blindness in the world. Also other diseases such as atherosclerosis and hypertension affect arteries and veins differently leading to an abnormal artery to vein width ratio (AVR) in retinal vasculature [1–4]. Ophthalmologists suggest that cardiovascular diseases may affect the length of vessels, increase their curvature and tortuosity, or modify the appearance of vessels. Therefore investigation of changes in arteries and veins might lead to significant foundations and deserves to be explored.

Manual assessment of subtle changes in arteries and veins is a cumbersome task and requires highly trained personnel. As a result, developing computer algorithms for this purpose are of paramount importance in assisting doctors for early identification and timely treatment of the associated diseases. An important pre-requisite for automated measurement of small changes in each type of vessels, is separation of arteries from veins. This task must be performed precisely in order to detect early signs of the mentioned diseases.

Automated classification of retinal blood vessels into arteries and veins is a difficult task and has been less explored in the

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literature. Arteries and veins are very similar in appearance. In addition, the curved shape of retina and inappropriate illumination conditions during image acquisition process might lead to non uniform illumination through retinal images. Also biological characteristics, in this case changes in color of retina from person to person, raise another problem [5,6].

There have been a number of methods reported in the literature for artery/vein classification of retinal blood vessels which fall into two categories: automated and semi-automated methods. The automated methods are based on feature extraction from major vessels. In those methods first, vascular network is separated from image background and other structures in the image. Then the centerline pixels or skeleton of vessels are extracted from the segmented vascular tree. For each centerline pixel, various features are calculated and finally each centerline pixel is assigned an artery or a vein label by classifier. In a semi-automated approach, first, initial points of main vessels are labeled by ophthalmologists as arteries or veins. Then those labels are propagated toward smaller vessels using the structural characteristics and connectivity information of the vascular tree. According to structural features of vascular tree, an artery or vein never crosses a vessel of the same type which means in a cross over point one vessel is artery and the other one is vein. Also three vessel segments connected to each other through a bifurcation point are of the same type of vessel.

The research work carried by Grisan and Ruggeri in 2003 [7] was among first attempts to separate arteries from veins automatically. The main idea behind their method was the symmetric division of the optical disk (OD) based retinal images into four partitions, feature extraction from vessels and applying fuzzy clustering classification to vessels in each partition independently. The results in each region were then combined and the total error rate of 12.4% for artery/vein classification in 24 images was reported. In another paper, Li et al. [8], adjusted a piece-wise Gaussian model to capture the central reflex feature of blood vessels which is more obvious in arteries than veins and Jelinek et al. [9], tested different classifiers and features in RGB and HSL color spaces for discrimination of arteries from veins. Also Konderman et al. [10] 2007 used features based on vessel profile at each centerline pixel as well as intensity values of pixels around those centerline points for classification of arteries and veins. They achieved 96.32% accuracy for classification of arteries and veins in 4 images. These methods are not comparable since they have been evaluated on different datasets most of which contain a few images.

In 2007 Rothaus et al. [11], proposed a semi-automated method for separation of artery map from veins. They assumed the vascular tree as a graph where intersection and bifurcation points are considered as vertices of the graph. The vessel segments connected at vertices were treated as edges of the graph. Utilizing an optimization problem they attempted to publish the manually labeled initial vessel points through the graph leaving the minimum conflicts possible using structural features of vessel tree. They have reported their results as the number of unresolved conflicts in vessel map. Niemeijer et al. [12], extracted features such as pixel intensity and average intensity values on profile of vessels in HSL color space. They have also exploit steerable Gaussian features from profiles of vessels at different angles in Green plane and classified the major vessels using kNN classifier. They have evaluated their method on publicly available database of DRIVE and achieved 88% area under ROC curve. V'azquez et al. [13], combined several feature vectors and clustering algorithms in regions of different radii from optical disk. They achieved the best results by dividing the image into four partitions and applying feature extraction to each partition separately repeating this process by rotating the image. Combining the results in the resulted overlapping regions they reported classification accuracy of 86.34% on VICAVR dataset which consists of 58 OD based retinal images. V'azquez et al. [14], raised this accuracy up to 91% by applying multi-scale retinex image enhancement to the images before feature extraction step.

Accurate classification of arteries from veins has been studied mainly for measurement of arteriolar-to-venular diameter ratio (AVR) [15–18] so far and is based on feature extraction from major vessels. The process of AVR estimation follows segmentation of vessels in a region of interest for measuring AVR [19,20] separation of major arteries from veins in the so-called region, and measuring the mean diameter of vessels in each class for calculation of final arteriolar-to-venular diameter ratio. However, extending those methods to a broader range of vessels is of high interest to ophthalmologists since will allow them to study the properties of each type of vessels independently and analysis the probable effects of micro vascular complications such as changes in curvature, branching pattern or appearance of vessels. For this purpose, structural characteristics of vessel network are exploited in order to publish the labels to smaller vessels that are hardly recognizable using their color features. Methods which use structural features are dependent on the quality of vessel segmentation and how much correctly labeled the major vessels are. Lack of information for finding connectivity of vessels at cross over and bifurcation points as well as publishing a wrong label may decrease the recognition rate considerably. Methods such as [21] use the manually labeled vessels as start points for spreading the labels. The method also requires user interference for revising the incorrectly labeled artery or vein trees found by their algorithm. To develop an automated method, initial points of vessels must be labeled using feature extraction. This process however, increases the probability of publishing a wrong label comparing to semi-automated method and thus requires the main vessels from which the thinner ones are traced to be classified with a high accuracy.

In this paper we present an automated method for classification of relatively major retinal vessels into arteries and veins. We intend to develop an automated method for separation of all vessels from which the secondary or small vessels are traced while we maintain the recognition rate of main vessel in the region of interest for AVR measurement comparable with previous methods. The final output of the proposed method is two binary images of artery and vein maps which can be used as start maps for spreading labels of major vessels toward small ones. Also the method may be used for determination of AVR.

The major contributions of the paper are as follow:

1. The proposed method in this paper achieves high classification rate without increasing the training samples or adding many features. By dividing the vessels many redundant sample points are removed.
2. Combination of image enhancement techniques such as histogram matching, CLAHE and MSRCR improves the results significantly.
3. We present an automated method which combines color features with structural features of vessel networks that leads to better results.
4. Also in this paper a new region separation scheme is proposed for improving the clustering classification of retinal blood vessels.

This paper is organized as follows: Section 2 is devoted to description of two datasets of retinal images used in this paper including publicly available dataset of DRIVE. In Section 3 the proposed method is explained which consists of three main steps including image enhancement, classification of vessels into arteries and veins and a post processing step for improving the classification rate obtained from previous step. In Section 4 experimental results are discussed in detail. Ultimately Section 5 concludes the research.

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