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An improved arteriovenous classification method for the early diagnostics of various diseases in retinal image

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ABSTRACT

(Background and objectives): Retinal artery and vein classification is an important task for the automatic computer-aided diagnosis of various eye diseases and systemic diseases. This paper presents an improved supervised artery and vein classification method in retinal image.
(Methods): Intra-image regularization and inter-subject normalization is applied to reduce the differences in feature space. Novel features, including first-order and second-order texture features, are utilized to capture the discriminating characteristics of arteries and veins.
(Results): The proposed method was tested on the DRIVE dataset and achieved an overall accuracy of 0.923.
(Conclusion): This retinal artery and vein classification algorithm serves as a potentially important tool for the early diagnosis of various diseases, including diabetic retinopathy and cardiovascular diseases.

1. Introduction

The retinal vasculature provides lots of information about various ophthalmic and systemic diseases, including diabetes mellitus and cardiovascular diseases. However, these diseases may affect arteries and veins differentially [1]. For instance, retinal veins are abnormally dilated in patients with diabetes mellitus and ipsilateral severe extracranial carotid diseases, while arteries are narrowed in high blood pressure [2,3]. Besides, these vascular changes often precede the onset of other signs and symptoms associated with these diseases, which makes the analysis of retinal vessels attractive as a biomarker for the early diagnosis and treatment. Therefore, it is of great interest to develop automated tools for retinal artery and vein classification.

The retinal artery and vein classification methods reported in literature can be divided into tree-based methods and feature-based methods. The former focuses on segmenting retinal vessels into individual biological vessel trees, which can be further classified into artery trees and venous trees. Rothaus et al. reported a semiautomatic approach using a rule-based method that can propagate vessel labels through the vascular graph, in which the labels were manually labeled by user as arteries or veins [4]. Hu et al. proposed a graph-based, meta-heuristic algorithm to separate vessel trees, which was evaluated on 48 fundus images with a false positive rate of 11.03% [5]. A recent work by Estrada et al. incorporated a graph-theoretic framework with a likelihood model, which needs iterative exploration of possible solutions to achieve optimized result. This method achieved a high accuracy of 91.78% from four different datasets [6]. Drawbacks of tree-based methods include the requirement for manual initial labels in some of the methods and the risk that a single mislabel along propagation may lead to mislabel of entire vessel tree, which is almost inevitable as the vessel tree goes to peripheral regions where low contrast is provided. Besides, complicated graph-based method usually asks for high computational cost and long running time. The second strategy is feature-based methods, which take advantage of the fact that retinal arteries and veins in standard retinal fundus imaging show a number of colorimetric and geometric differences [7]. Specifically, arteries contain oxygenated hemoglobin, which has higher reflectance than deoxygenated hemoglobin in specific wavelengths, and are thus brighter than veins. Besides, the central light reflex (CLR) phenomenon, a specular reflection, is more frequently seen in retinal arteries. Various methods have been developed for retinal artery and vein classification based on a single or a combination of these features. For instance, Niemeijer et al. reported a supervised classification method using a k-nearest neighbor (kNN)

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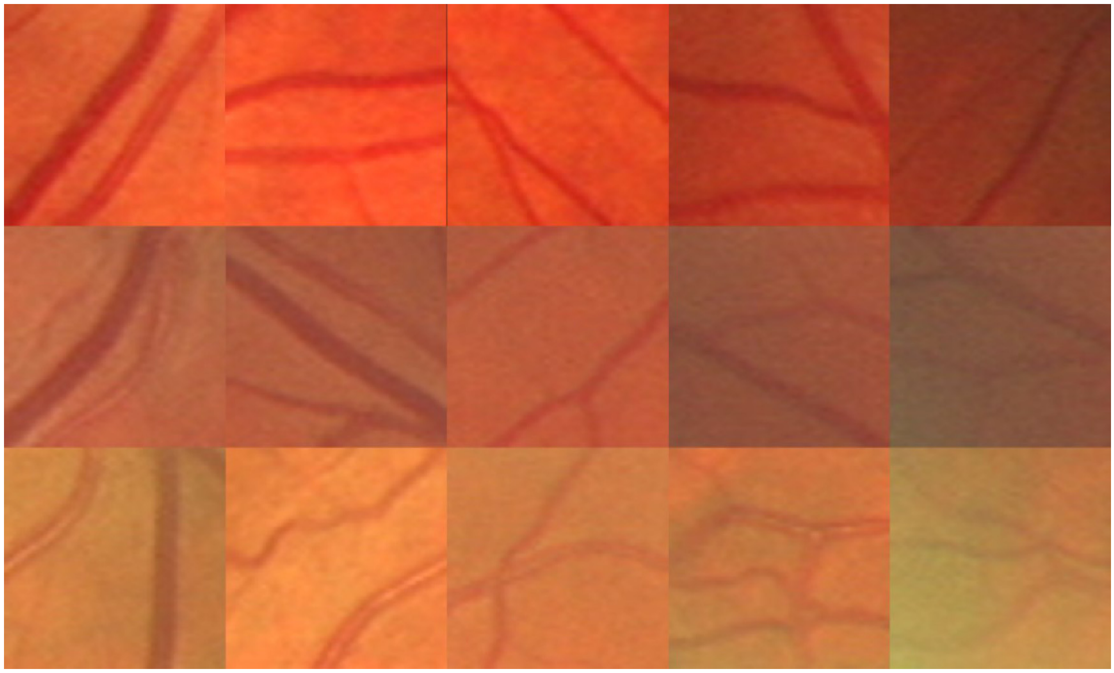

Fig. 1. Examples of intra-image and inter-subject differences. From left to right: inset view of retinal blood vessels from central region to peripheral region of the same image. From top to bottom: inset view of retinal blood vessels from different subjects.

classifier, in which HSV color features and Gaussian derivatives were used as discriminating features and an area under the receiver operator characteristic (ROC) curve of 0.88 was reported [8]. Saez et al. reported an unsupervised method based on a clustering algorithm to distinguish arteries and veins using RGB/HSL color and gray level as the discriminating features, which gave a sensitivity of 0.78 for arteries and 0.87 for veins [9]. However, several important characteristics of retinal images are neglected in these methods. First, retinal image suffers from an inherited inhomogeneous brightness caused by uneven illumination during image acquisition, resulting in very different appearances of blood vessels near the center of the image and at peripheral regions, which can be even larger than the differences between arteries and veins. Moreover, the inter-subject background varies a lot due to biological characteristics (as shown in Fig. 1), showing different distributions in feature space. To address these, Vazquez et al. proposed a retinex image enhancement method to adjust the uneven illumination inside an image, which improved the classification result to an accuracy rate around 90% [10]. Relan et al. reported an unsupervised method based on a Gaussian mixture model and an expectation-maximization clustering on illumination-corrected retinal images, which gave an accuracy of 0.87 for veins and 0.85 for arteries [11]. Although improvement has been achieved in these methods through considering intra-image differences, inter-subject differences were not considered. Besides, relatively simple features, such as different RGB and HSV color spaces, have been considered as discriminating features in most reported methods. We propose that more complicated features may be more efficient in distinguishing retinal arteries and veins. For example, the exact vessel width can reflect the major geometric difference between arteries and veins while the image texture is able to show not only color features but also geometric features, including the sharpness of vessel boundary and the coarseness inside a blood vessel [12]. Thus, we introduce several novel features in this work trying to improve the efficiency of classification.

In this paper, we propose to improve the retinal artery and vein classification in two ways. First of all, background adjustment is applied to decrease the intra-image differences, *i.e.*, the differences between central region and peripheral regions. Moreover, an inter-subject normalization is introduced to minimize the color differences between subjects. Second, we introduce several novel features, including the exact vessel width and the first and second order texture features.

2. Materials

The vessel classification method was evaluated on a popular publicly available database, the DRIVE (Digital Retinal Image for Vessel Extraction) database, which includes a set of forty color fundus photographs obtained from a diabetic retinopathy screening program [13]. In this dataset, seven out of forty images contain pathologies such as exudates, hemorrhages and pigment epithelium changes. The images, with a size of 768×584 pixels, were acquired using a Canon CR5 non-mydriatic 3-CCD camera with a field-of-view (FOV) of 45°. DRIVE database is divided into two sets, the training set and the test set, each containing twenty images. The test set, manually segmented by two observers and the first observer is accepted as ground truth, was included in this study. The vessels from the test set was manually labeled as artery, vein, or overlapping by a trained ophthalmologist.

3. Methods

The flowchart of our approach is given in Fig. 2. Initially, the intra-image regularization and inter-subject normalization is applied and the blood vessels are extracted based on image salient features. During training phase, multiple image features are extracted from each vessel centerline pixel and a likelihood model is established. During test phase, the same features are extracted for each centerline pixel and classified using a kNN classifier. For each test pixel, the output value of the classifier is the average of the labels of the k nearest neighbors in feature space, resulting in a gray-scale probability image. In this image, lower gray level indicates a higher probability of being a vein while higher gray level indicates a higher probability of being an artery. At last, a voting