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Retinal vessel segmentation in colour fundus images using Extreme Learning Machine

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ABSTRACT

Attributes of the retinal vessel play important role in systemic conditions and ophthalmic diagnosis. In this paper, a supervised method based on Extreme Learning Machine (ELM) is proposed to segment retinal vessel. Firstly, a set of 39-D discriminative feature vectors, consisting of local features, morphological features, phase congruency, Hessian and divergence of vector fields, is extracted for each pixel of the fundus image. Then a matrix is constructed for pixel of the training set based on the feature vector and the manual labels, and acts as the input of the ELM classifier. The output of classifier is the binary retinal vascular segmentation. Finally, an optimization processing is implemented to remove the region less than 30 pixels which is isolated from the retinal vascilar. The experimental results testing on the public Digital Retinal Images for Vessel Extraction (DRIVE) database demonstrate that the proposed method is much faster than the other methods in segmenting the retinal vessels. Meanwhile the average accuracy, sensitivity, and specificity are 0.9607, 0.7140 and 0.9868, respectively. Moreover the proposed method exhibits high speed and robustness on a new Retinal Images for Screening (RIS) database. Therefore it has potential applications for real-time computer-aided diagnosis and disease screening.

1. Introduction

The retinal vessels are the only part of the blood circulation system of human that can be non-invasive observed directly (Resnikoff et al., 2004; Mehriban and Chen, 2012). Many systemic conditions such as diabetes, hypertension, arteriosclerosis, and cardiovascular disease can be found by the retinal vasculature examination. Therefore, the attributes of the retinal vessel such as width, tortuosity, branching pattern and angles play significant role in early disease diagnosis. Furthermore, various pathological changes of retinal vessels are direct reflections of fundus disease, such as diabetic retinopathy (DR), glaucoma, age-related macular degeneration (AMD) and so on. Taking DR as an example, it is the first place blinding disease in working-age population (Kirbas and Quek, 2004). According to statistics of International Diabetes Federation (2013), the number of the patients with diabetes is up to 342 million all over the world and Chinese diabetic patients reached 98 million in 2013. With the increase of the patients, blindness rate caused by DR also goes up year by year. To save medical resources and reduce workload of clinicians, automatic retinal vessel segmentation with high accuracy and speed is remarkably necessary (Winder et al., 2009).

For the clinical indicators of retinopathy, 2-D colour fundus image and 3-D optic coherence tomography (OCT) image are well accepted and commonly used for ophthalmic diagnosis (Abràmoff et al., 2010). Due to the ease of computation and low cost properties, it is more frequently to use the colour fundus image than OCT image in most clinical diagnosis and large-scale screening. And lesions can be observed clearly in the colour fundus images, neovascularizations, microaneurysms, hemorrhages, venous beading, hard exudates, cotton-wool spots, macular oedema and intraretinal microvascular abnormalities (IRMA), as shown in Fig. 1. So this paper focuses on automatic retinal vessels segmentation in 2-D colour fundus image.

In this paper, a supervised method is proposed to segment retinal vessel based on Extreme Learning Machine (ELM) (Huang et al., 2006). As shown in Fig. 2, the proposed scheme consists of training and segmenting components. During the training phase, a feature vector is extracted for each pixel of training image firstly, encoding

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0895-6111/

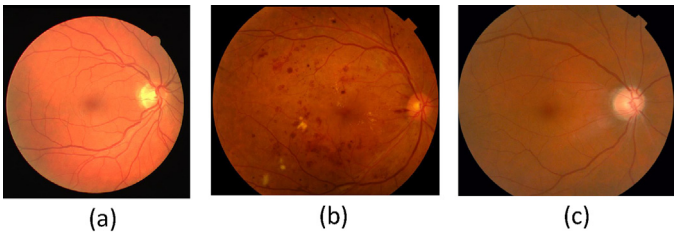

Fig. 1. Illustration of the colour fundus images. (a) Healthy image. (b) Abnormal image of DR. (c) Abnormal image of glaucoma.

information on the local intensity, morphological transformation, phase congruency, Hessian and divergence of vector fields. Then, we obtain a classifier by the feature vector and the manual labels as the input of ELM. In the segmenting phase, the feature vector extracted from the segmenting image is used as the input of the classifier which has been obtained in the training phase. The output of classifier is the binary retinal vascular segmentation. Finally, an optimization processing is implemented to remove the region less than 30 pixels which is isolated from the retinal vascular.

The key points of our proposed work in this paper are as follows:

(1) The discrimination feature like phase congruency of the vector field is constructed to enhance the robustness of vessel segmentation.
(2) The ELM based classifier is modelled to fast and accurate retinal vessels segmentation in fundus images.
(3) We create a new Chinese fundus image database, Retinal Images for Screening (RIS), consisting of 15 images with manual labelled retinal vascular for computer-aided diagnosis.

The experimental results on the public Digital Retinal Images for Vessel Extraction (DRIVE) database demonstrate that the proposed method is efficient and robust on the fundus images with lesions compared with other methods. The average accuracy, sensitivity, and specificity of our method are 0.9607, 0.7140 and 0.9868, respectively. Meanwhile, the proposed method also exhibits high robustness on a new Retinal Images for Screening (RIS) database. The fundus images of the RIS database are captured from the Department of Ophthalmology, the Second Xiangya Hospital of Central South University. The most important of all, the running time of the proposed method is very fast. It has potential applications for real-time computer-aided diagnosis and disease screening.

2. Related work

In recent years, many related works have been done for retinal blood vessel segmentation in fundus images which can be approximately divided into five categories: learning-based implementations, matched filtering, morphological processing, vessel tracing, and model based approach (Fraz et al., 2012a). The learning-based vessel segmentation approach is widely used by means of supervised and unsupervised algorithms.

Supervised approaches learn a model to decide whether a pixel belongs to a vessel or not with the help of manual label, where the manual segmented training images are termed as the gold standard. So the supervised methods show an excellent performance in comparison with other approaches reported. The related research in this field is introduced as follows.

Staal et al. reported a segmentation method based on image ridges extraction (Staal et al., 2004). The ridge pixels are grouped into convex sets that represent approximately straight line elements. Meanwhile the authors obtained a fundus image database named DRIVE from a screening program, which is widely used for the testing of fundus images processing technology. Soares et al. presented a supervised method for retinal vessel segmentation in Soares et al. (2006), by constructing a feature vector which consists of pixel intensity and 2-D Gabor wavelet transform responses at multiple scales. Then a Gaussian mixture model is used to classify the image pixel into two classes: vessel point or background.

A method using linear operators and Support vector machines (SVM) is proposed by Ricci and Perfetti (2007). Two segmentation

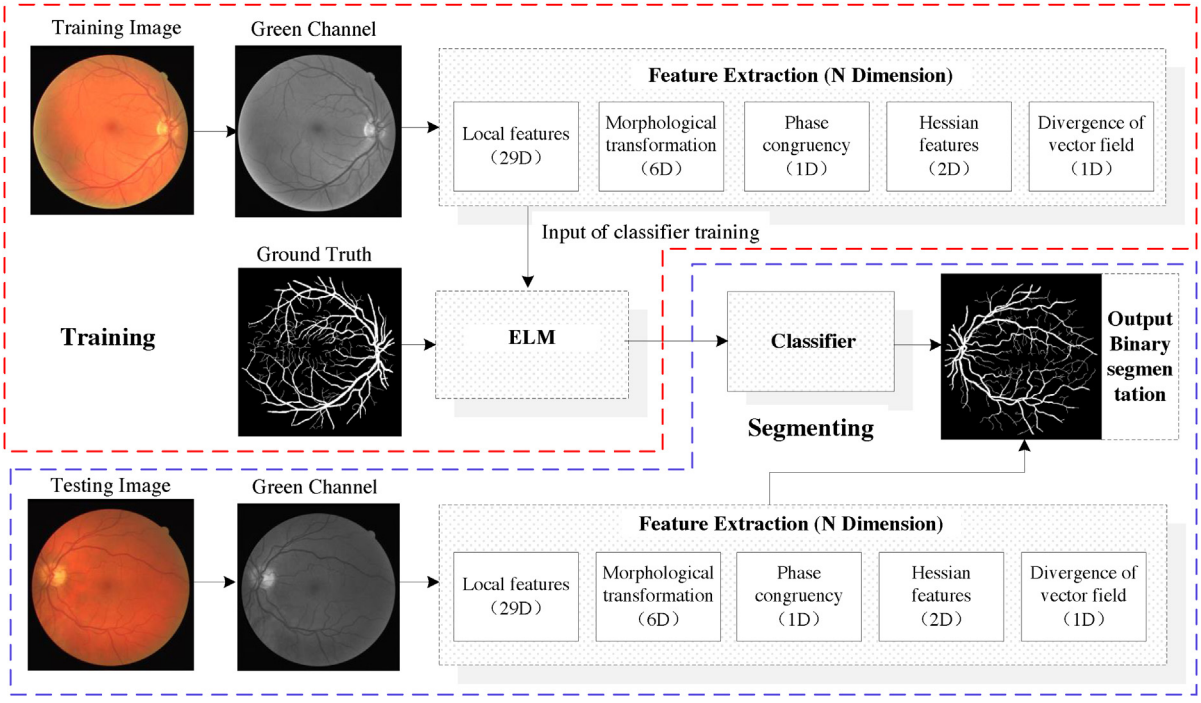

Fig. 2. Flowchart of the proposed method.