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Review Article

Automatic parameters selection of Gabor filters with the imperialism competitive algorithm with application to retinal vessel segmentation

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ABSTRACT

Retinal images play an important role in the early diagnosis of diseases such as diabetes. In the present study, an automatic image processing technique is proposed to segment retinal blood vessels in fundus images. The technique includes the design of a bank of 180 Gabor filters with varying scale and elongation parameters. Furthermore, an optimization method, namely, the imperialism competitive algorithm (ICA), is adopted for automatic parameter selection of the Gabor filter. In addition, a systematic method is proposed to determine the threshold value for reliable performance. Finally, the performance of the proposed approach is analyzed and compared with that of other approaches on the basis of the publicly available DRIVE database. The proposed method achieves an area under the receiver operating characteristic curve of 0.953 and an average accuracy of up to 0.9392. Thus, the results show that the proposed method is well comparable with alternative methods in the literature.

1. Introduction

The retina is the only location in the human body where blood vessels can be directly captured noninvasively in vivo. Retinal blood vessels constitute the fundamental subject of screening systems and play an important role in automatic retinal disease detection [1,2]. Accurate segmentation and detection of the retinal vasculature could facilitate the evaluation of retinopathy of prematurity; detection of arteriolar narrowing;

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measurement of vessel diameter for diagnosing diseases such as diabetes, arteriosclerosis, and hypertension; and computer-assisted laser surgery [3,4]. Recently, the application of image processing in ophthalmology has attracted considerable attention as an important step in detecting blood vessels [5,6]. Retinal vascular segmentation techniques are based on the contrast between the retinal blood vessels and the surrounding background. Manual segmentation of blood vessels in retinal images is a tedious task that requires training. Automatic quantification of retinal vessels has been widely accepted as the first step in the development of a computer-assisted diagnostic system for ophthalmic diseases. Many approaches and algorithms have been proposed for the segmentation of retinal vessels [7]. We present a brief review of some common algorithms. The use of a matched filter for retinal vessel segmentation was first proposed in [8,9]. This filter convolves a 2-D kernel with the retinal image to detect the vessels and effectively enhances vessel segmentation by assuming that the intensity profile of a vessel can be approximated by a Gaussian curve and that the width of the vessels is constant. The matched filter for detecting blood vessels is convolved with the given image at several scales, and in each pixel, the maximum response is recorded.

The ridge-based vessel segmentation method was introduced by Staal et al., who assumed that vessels are elongated structures [10] and extracted image ridges to be used as primitives to conduct line elements. In each part, a local coordinate corresponding to the line element is defined. Then, for each pixel, 27 features are computed and the best one among these is classified using a *k*-nearest-neighbor classifier and sequential forward feature selection methods. An adaptive local thresholding using a verification-based multi-threshold probing algorithm is proposed in [11]. In this method, a series of different thresholds is applied. Then, classification of the binary image obtained is performed to accept or reject any region as a certain object. The final detection result is a combination of the results based on the individual thresholds. The authors in [12] presented an advanced method based on Combination of Shifted Filter Responses (COSFIRE) for the automatic segmentation of vessel trees in retinal fundus images. They evaluated the proposed method the proposed method on DRIVE, STARE and CHASE_DB1 datasets. In [13], a delineation method base on B-COSFIRE and Generalized Matrix Learning Vector Quantization (GMLVG) for vessel detection is proposed. The proposed method is evaluated on DRIVE and STARE datasets for detection of tiny vessels in fundus images.

The authors in [14] investigated a retinal regimentation method based on cake filter on STARE dataset. In the proposed method, the cake filter is used to fuse the real components of orientation scores and combined with an adaptive threshold for getting retinal vascular network. In another study [15], the researchers used a feature extraction method based on Gabor filter and line operator. They extracted a feature vector consisting pixel intensity and Gabor transformation coefficients for each pixel of the retinal image. The extracted features applied to the support vector machine and Bayesian classifiers. In one study [16], researchers proposed a multi-scale, multi-directional Gabor wavelet transform using a supervised classification algorithm, namely, linear minimum squared error (LMSE). They constructed a feature vector containing pixel intensity and maximum response obtained of Gabor filter at different scales. The vessel tracking method follows vessel center lines to determine the vascular structure [17,18]. This method starts from an established initial set of points. Then, the vessels are traced by using local information to determine the most appropriate candidate pixel from among those close to the one under evaluation. A morphological processing, i.e., a combination of morphological filters and cross-curvature evaluation, to detect the vascular network from fundus images is introduced in [19,20]. Mathematical morphology highlights vessels in retinal images by exploiting the fact that the vessels are linear and connected with a smoothly varying curvature along the crest line. Cross-curvature evaluation is performed to identify the structures in a retinal image that have a linearly coherent curvature. Because the values of pixels in binary images are restricted to 0 or 1, morphological filters are applied to gray-scale images. In addition, applying such filters to binary images is a simple procedure that involves counting of pixels as compared to weighted multiplication.

Two-dimensional Gabor wavelets, introduced by Soares et al., employ a Gaussian mixture model to classify each pixel as either a vessel or a non-vessel pixel [21]. For feature detection and vessel enhancement, multi-scale analysis is conducted on the image using Gabor wavelets. After converting each pixel in a given image into a green component, the maximum response of the Gabor transform is considered over angles at four different scales.

The most recent studies discuss algorithms for automatic detection of diabetic retinopathy in retinal images. Based on the above-mentioned methods, Gabor filters have played a fundamental role in the understanding of visual processing in different contexts. These filters have been employed in many image processing techniques to address issues such as image coding, texture segmentation, face recognition, and edge detection of special oriented structures [22]. Vessels in retinal images are connected and piecewise linear; therefore, for segmenting such images, Gabor filters are well suited to detect oriented features [23]. Moreover, Gabor filters are directional and can be tuned to specific frequencies; thus, they can be adjusted for vessel enhancement and noise filtering in a single step. In addition, they have been shown to outperform other oriented feature detection approaches. These characteristics have motivated the adoption of Gabor filters in the present study.

This work is accomplished in steps to achieve high-performance retinal blood vessel segmentation. First, 180 Gabor filters with a rotation of 1° are used to capture the edge data of retinal vessels. The maximum response of each image is selected to determine the approximate vessel edge location. However, we later establish that 20 directions are sufficient. Second, an optimization method, namely, the imperialism competitive algorithm (ICA), is employed to automatically select the parameters of the Gabor filters. In addition, a systematic approach is adopted to determine an effective threshold value. Finally, the performance of the proposed approach is evaluated using images obtained from the Digital Retinal Image for Vessels Extraction (DRIVE) database [24].

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