Combination of Matched Filter and Gabor Filter for Retinal Vessel Extraction

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Abstract: In this paper a method is proposed to fine-tune the performance of matched filter using a Gabor filter structure to improve the overall vessel segmentation accuracy. The proposed Gabor filter structure classifies each pixel as vessel or non-vessel based on the output of matched filter and several other features extracted on the pixel level. The vessels are detected by thresholding the retinal image's response to the matched filter, while the threshold is adjusted by the image's response to the Gabor filter.The ground truth output is available from images labelled manually by observers. Several experiments were conducted to achieve better performance for matched filter and the error in pixel segmentation between the available ground truths.

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1. Introduction

Detection of blood vessels has great medical importance as it aids in diagnosis and detection of many diseases such as diabetes, hypertension, arteriosclerosis, cardiovascular disease and stroke. Manual segmentation (detection) of blood vessels by ophthalmologist is slow and lengthy process. Automatic vessel detection techniques simplify and accelerate the process of vessel detection. Matched filter is one of the most important methods for automatic detection of blood vessels in digital retinal images. The matched filter is a simple yet effective method for vessel extraction. In this paper, we propose a new algorithm to detect and extract blood vessels in ocular fundus images. The proposed algorithm is composed of three steps, matched filtering, Gabor based thresholding, and vascular intersection detection. Compared with the method in [1, 2], our proposed algorithm is fully automatic. Since our algorithm can determine one optimal global threshold value, it requires less computational complexity compared to [2] and [7].

This paper is organized as follows: Section 2 briefly reviews the Matched Filter. Section 3 presents the proposed Gabor Filter scheme. Section 4 presents experimental results. The conclusion of this paper is given in section 5.

2. Matched Filter

The Matched filter was first proposed in [3] to detect vessels in retinal images. It is useful that we propose a prior knowledge that the cross-section of the vessels by a Gaussian function be approximated. The implication of matched filter detection is used to detect piecewise linear segments of blood vessels in retinal images. Blood vessels usually have poor local contrast. For enhance of the blood vessels the two-dimensional matched filter kernel is designed and convolved with the original. A matched filter kernel is expressed as

$$f(x,y) = -\exp\left(\frac{-x^2}{2\sigma^2}\right), \quad for\,|y| \le L/2, \qquad (1)$$

L is the length of the segment. Here, for smoothing of noise the direction of vessel is assumed to be aligned along the y axis. The kernel needs to be rotated for all possible angles for this reason a vessel may be oriented at each possible angles. In [3], 12 different kernels have been built to confine all possible orientations. A set of twelve 16×15 pixel kernels is applied by convolving to a retina and at any possible pixel only the maximum of their replications is retained. In this paper we propose that f(x, y) be rotated to detect the vessels of different orientations. In this case the matched filter makes it popular in vessel detection. After thresholding, the vessel and non-vessel edge will be detected. In other word, the aim of this paper is to find a simple filtering technique to determine the vessels from non-vessel.

3. Gabor Filter and Proposed Method

First, a Gabor filter is introduced by Dennis Gabor. Gabor filter is a linear filter that used for edge detection. In human visual system, orientation and frequency delegations of Gabor filters are analogous and they have been found to be particularly proper for texture representation and discrimination. A 2 dimensional Gabor filter is a Gaussian kernel function that shaded by a sinusoidal sheet wave. The all of Gabor filters are self-similar and these filters can be generated from one mother wavelet by rotation and stretch. Thus, retina image analysis by the Gabor filters is similar to realization in the human visual system. Gabor filter's impulse response is defined by a harmonic function manifold by a Gaussian function. Because of the multiplication convolution property, the Fourier transform of a Gabor filter's impulse response is the convolution of the Fourier transform of the harmonic function and Gaussian function. The Gabor filter has both real and imaginary part demonstrating orthogonal directions [6]. The two parts may be formed into a complex number or used particularly.

Complex:

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma)= \exp(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2})\exp(i(2\pi\frac{x'}{\lambda}+\psi)) \quad (2)$$

Real:

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma)= \exp(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2})\cos(2\pi\frac{x'}{\lambda}+\psi) \quad (3)$$

Imaginary:

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma)= \exp(-\frac{x'^2+\gamma^2 y'^2}{2\sigma^2})\sin(2\pi\frac{x'}{\lambda}+\psi) \quad (4)$$

where

$$x' = x\cos\theta + y\sin\theta \quad (5)$$

and

$$y' = -x\sin\theta + y\cos\theta \quad (6)$$

In this equation, λ represents the wavelength of the sinusoidal factor, θ represents the orientation of the normal to the parallel stripes of a Gabor function, ψ is the phase offset, σ is the sigma of the Gaussian envelope and γ is the spatial aspect ratio, and specifies the ellipticity of the support of the Gabor function. Figure 1 shows the images of Gabor filter kernels with values of the orientation parameter of 0, 45 and 90, from left to right, respectively.

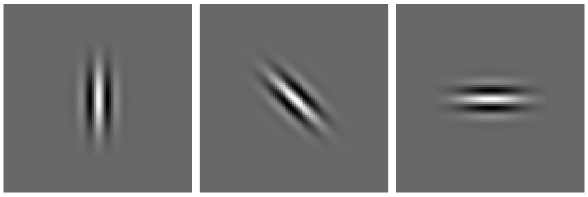

Fig. 1: Gabor filter kernels, the parameters are: $\lambda = 10$, $\psi = 0$, $\gamma = 0$ and bandwidth 1.

To this end, we propose a thresholding scheme by using the Gabor filter for retinal vessel detection. The threshold is applied to the retinal image's response to matched filter but the threshold level is adjusted by the image's response to Gabor filter. After filtering the retinal image with the Gabor filter, two response images, H (by the matched filter) and D (by the gabor filter) are obtained. The local mean image of D is calculated by filtering D with a mean filter:

$$D_m = D * W \quad (7)$$

where W is a $w \times w$ filter whose elements are all $1/w^2$. The local mean image D_m is then normalized so that each element is within [0, 1]. We denote by $\overline{D}_m$ the normalized image of D_m. The threshold T is then set as

$$T = (1+\overline{D}_m).T_c \quad (8)$$

where T_c is a reference threshold. In this paper, we set T_c as follows:

$$T_c = c.\mu_H \quad (9)$$

Where μ_H is the mean value of the response image H, and c is a constant which can be set between 2 and 3 based on our experiment experience. By applying T to H, the final vessel map M_H is obtained as

$$\begin{cases} M_H = 1 & H(x,y) \geq T(x,y) \\ M_H = 0 & H(x,y) < T(x,y) \end{cases} \quad (10)$$

It can be seen from (7)–(10) that if there is a vessel in the image, then at the corresponding area the magnitude in $\overline{D}_m$ will be weak, and hence the threshold T_H will be lowered. Thus this vessel can be easily detected by (10). If there are some non-vessel structures in the image, the corresponding magnitude in $\overline{D}_m$ will be high, and hence the threshold T_H is raised. Thus these non-vessel edges can be suppressed.

4. Experimental Result

We tested the proposed method on two publicly available databases, the STARE database [5] and the DRIVE database [1]. The results of the manual segmentation are available for the two sets. For the images in the test set, a second independent manual segmentation is also available. The proposed method outlined for database images were implemented using the Matlab programming language and run on a PC with an Intel, Duo CPU 2.00 GHz, 2.00 GHz of RAM machine and yielded the results in the Fig. 2, 3 and TABLE I, II.

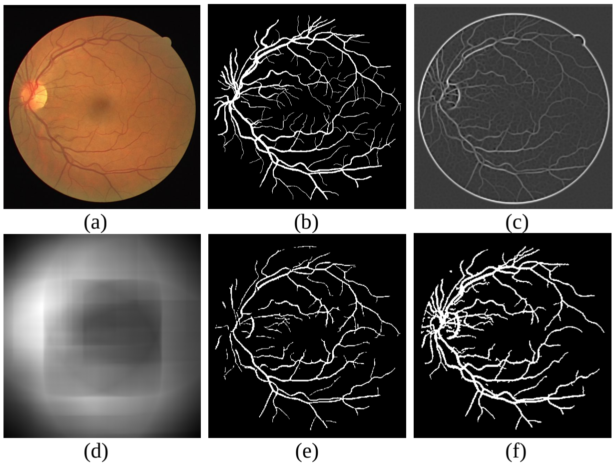

Fig. 2: Illustration of the proposed retinal vessel extraction scheme: (a) the original image 1 from the DRIVE database, (b) the ground truth vessel map (c) the response map to matched filter, (d) the local mean of the response to Gabor, (e) the vessel extraction result the MF response map, and (f) the extraction result of the proposed method

4.1. Segmentation Assessment

In order to assess the algorithm performance, three measures are used: true positive rate (TPR), false positive rate (FPR), and accuracy (ACC). Assume TP and TN show the blood vessel pixels and background pixels, which correctly detected, respectively. FP shows the pixels not belonging to a vessel, but is recognized as blood vessel pixels, and FN shows the pixels belonging to a vessel, but is recognized as background pixels, mistakenly. Based on the aforementioned definitions, TPR, FPR, and Accuracy are defined as follows:

$$TPR = \frac{TP}{TP + FN} \qquad (11)$$

$$FPR = \frac{FP}{FP + TN} \qquad (12)$$

TABLE I: Vessel extraction results for the DRIVE database.

Method	TPR	FPR	Accuracy
Staal [1]	0.7194	0.0227	0.9442
Soares [2]	0.7283	0.0212	0.9466
Mendonça [7]	0.7344	0.0236	0.9452
Proposed Method	**0.7110**	**0.0278**	**0.9380**

$$ACC = \frac{TP + TN}{TP + FP + TN + FN} \qquad (13)$$

Table I and II shows the comparison of performance of our method with the other approaches in terms of TPR, FPR, and accuracy.

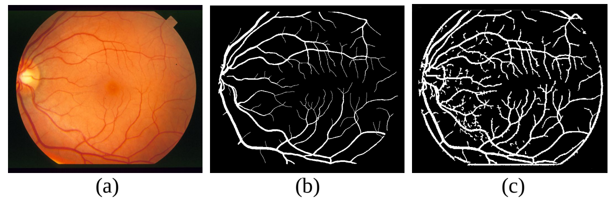

Fig. 3: Illustration of the proposed retinal vessel extraction scheme: (a) the original image im0077 from the STARE database, (b) the ground truth vessel map (c) the extraction result of the proposed method

TABLE II: Vessel extraction results on the STARE database.

Method	TPR	FPR	Accuracy
Staal [1]	0.6970	0.0190	0.9516
Soares [2]	0.7165	0.0252	0.9480
Hoover [5]	0.6751	0.0433	0.9267
Proposed Method	**0.7170**	**0.0250**	**0.9482**

5. Conclusion

In this paper a new method for retinal vessel extraction approach has been used. The proposed method is successfully developed; it obtained for better implementation over the other vessel extraction as has been proven for the simulation results. Experimental results show that the proposed method insensitive to noise and is also can preserve the detail of the object. In addition, our proposed algorithm can be used to reduce the capacity of more computational tasks in research.

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