The Comparison of Retinal Vessel Segmentation Methods in Fundus Images

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Abstract. Due to complexity of retinal fundus images, they are usually affected with noise and lighting during image acquisition. It brings difficulty to segment retinal vessels accurately, so accurate retinal vessel segmentation is still a challenging task in fundus images analysis. Five kinds of typical retinal vessel segmentation methods are briefly introduced in this paper, which are based on thresholding, matched filtering, mathematical morphology, tracking, and deep learning. Each method has its own characteristics. The experiment results show that the method based on deep learning is the best segmentation method among them, which can effectively assist doctors to detect and diagnose cardiovascular and ophthalmic diseases in early stage, and provide the decision support for ophthalmic disease computer-aided diagnosis and establishment of large-scale screening system.

Keywords: Image Segmentation, Retinal Vessel Image, Deep Learning

1 Introduction

The retinal vessels at the bottom of eyeball are the only part of vascular system that can be directly observed noninvasively, cardiovascular diseases and stroke are related to their morphological structure changes, such as shape, curvature, branching pattern and width. Retinal vessel image analysis plays an important role in clinical fields, some of diseases listed above such as glaucoma, diabetic retinopathy, and macular degeneration are very dangerous. If they aren’t detected correctly in time, they can lead to blindness [1-3]. In recent years, the exploration of retinal blood vessel segmentation method has been widely concerned by researchers. Generally, retinal vessels of fundus images was segmented manually by specialists, but it is an expensive procedure in terms of segmenting time and energy, lacking of repeatability and reproducibility. It is not good for clinic diagnosis or large-scale screening. For this reason, accurate and automatic segmentation approach is crucial in computer aided-diagnosis [3,4]. It many help eye specialists and ophthalmologist to discern the related diseases in early days and treatment evaluation. Due to the complexity of retinal vessel image and the influence of noise and light during the process of image acquisition, it is still a challenging task to segment retinal image accurately.

Many retinal vessel segmentation methods have been proposed in recent decades [1-5]. According to the principle of whether characteristic data provided by standard image will be used in retinal vessel segmentation, they may are generally fall into two categories: the supervised and the unsupervised...
methods. The latter make use of prior knowledge on the structure of vessels and usually rely on rule-based schemes, but the former are coming under machine-learning methods where pixels are marked either as vessels or non-vessels. Similarly, according to its inherent characteristics, it can be roughly divided into five kinds methods of segmenting: thresholding, matched filtering, mathematical morphology, tracking and deep learning. Usually, one of them will has its limitations, some methods are often combined to achieve better retinal vessel segmentation performance. We aim at providing comprehensive information for these typical retinal vessel segmentation methods by summarizing their advantages and limitations in this paper.

2 Several Typical Retinal Vessel Segmenting Methods

2.1 Method Based on Thresholding

Many thresholding methods have been proposed for segmenting retinal vessel images. Among them, Jiang et al. [4,5] used several different thresholds to segment retinal vessel after image binarizing. Hoover et al. [6] used threshold decreasing and regional feature analysis to extract retinal vessels. Roychowdhury et al. [7] presented a segmentation technique where new pixels generated iteratively by using global adaptive threshold for vessel approximation. Temitope [4,5] used local adaptive threshold segmentation to segment retinal vessels based on GLCM capability information, it can obtain better segmenting performance with a lower running time and compared to other traditional thresholding ones. Jyotiprava Dash[8] presented an automated segmenting approach that carried out with three stages: pre-processing, vessel extracting and post-processing, the required retinal vessels was detected from background by using mean-C thresholding after pre-processing stage. Luiz [2]obtain the intensity threshold \( r \), that consists in searching for gray level intensity value, the threshold can be expressed as follows

\[
r_i = \arg \max \left\{ \frac{f(l) + \Delta_i (1 - l) - 1}{\sqrt{1 + \Delta_i}} \right\}
\]

2.2 Method Based on Matched Filtering

The method based on matched filtering segment retinal vessel images by making full use of the correlation between local image block and filter kernel, and uses a two-dimensional Gaussian template to perform a two-dimensional convolution operation on retinal vessel image, reproduces retinal vessel structure in width and direction. Chaudhuri et al. [1,4,5] proposed a two-dimensional matched filtering segmentation method, which used a Gaussian curve to approximate retinal vessel cross-section, and then searched for all vessel information in fundus image based on a Gaussian convolution method. The B-COSFIRE filter algorithm proposed by Azzopardi et al. [9], he set two rotation-invariant B-COSFIRE filters to select lines and line endpoints respectively, and realizes the segmentation of blood vessel pixels by limiting the threshold. Zhang et al. [1,4] proposed a multi-scale 2-order Gaussian derivative filtering response segmentation technique based on maximizing directional fractional domain. Jaspreet et al.[10] put forward an method based on Gabor filter and gray co-occurrence matrix. The common Gauss matched filtering can be expressed as follows[2,9]:

\[
G(x, y) = e^{-\frac{1}{2} \left( \frac{x}{\sigma_1} \right)^2 + \frac{y}{\sigma_2}^2}
\]

2.3 Method Based on Mathematical Morphology

According to the linear connection characteristics of retinal vessels, fund image pixels are divided into two categories: vessels and background. Fraz et al. [4,5]adopted vessel skeletal recognition with morphological bit planes to segment vessels, they used the first derivative of Gaussian filter and top hat transform of morphology to achieve retinal vessels segmentation image. Imani et al. [11] combined with morphological component analysis (MCA) and Morlet wavelet transform to separate retinal
vessels. Karthika et al. [4] classified candidate ridges based on curvelet transform and multi-structural element morphological reconstructing, combined with strong connected component analysis and maximum inter-class variance method. Klein et al [1,4] proposed a morphological method to segment vessels from vascular images, which uses a geometric model to distinguish all unexpected patterns that may affect retinal vessels. The Top-hat of image A by structuring element B as described in the following formula:[2,12]

\[
\text{Top\_hat}(A) = A - (A \circ B)
\]  

(3)

2.4 Method Based on Tracking

The method based on tracking sets an initial seed pixel point on centerline or edge of retinal vessel at first, seed points can be either manually defined or obtained through vessel enhancing technique. Then, based on the initial seed point, from this point, iteratively tracking retinal vessel according to the characteristics of retinal vessels, tracking the whole vessel tree along retinal vessel centerline. The method is generally divided into semi-automatic and full-automatic vessel tracking algorithm. The former depends on the determination of starting point, and has been gradually replaced by automatic vessel tracking algorithm. Yin et al [3,5] proposed a tracking method based on probability tracking. Liu et al. [1,4] was the first proposed tracking algorithm of manually determining initial point, and continuously found new starting points in the remaining vessels for re-segmentation to achieve the final segmentation. Vlachos et al. [13] found some brightest points from retinal vessel pixels as starting point. Chutatape et al. [14] tracked the centerline of subsequent vessels based on the known centerline of retinal vessel on the basis of Gaussian filtering and Kalman filtering. The flow chart of tracking methods is shown as following[1]:

![Flow chart of methods based tracking](image)

2.5 Method Based on Deep Learning

With the rapid development of deep learning technology, the application of deep learning in medical image segmentation is enlarging, it mainly includes FCN (Convolutional Neural Network), U-net neural network and RNN (Recurrent Neural Network). Wang et al. [15] segmented retinal vessel images by combining random forest with CNN. Li et al. [4,5] proposed a cross-modal method using a deep automatic encoder, using deep neural networks to simulate the relationship between retinal images and vessel images to segment retinal vessels. Liang et al. [16] proposed a U-net network with adaptive information to segment retinal blood vessel images, they added dense variable convolution and pyramidal hole convolution operations to U-net to improve segmentation performance. Son et al. [17] used a generative adversarial network (GAN) method to segment retinal vessels images and optic discs, which achieved good performance on ROC curve and PR curve.

The flow chart of retinal vessels segmenting methods based on deep learning is shown as follows[16]:

![Flow chart of methods based tracking](image)
3 Evaluation Index for Retinal Vessel Segmentation

As usual, segmentation performance is evaluated with respect to manually performed by an expert clinician. The retinal fundus image consists of retinal vessels and background, the segmentation problem can be regarded as a problem of binary classification on all pixels. The True Positive (TP), True Negative (TN), False Negative (FN), and False Positive (FP) are generally used[1,5], where positive and negative refer to pixels belonging to vessels and background according to manual segmentation, respectively. In order to assess the performance of five typical methods, the Sensitivity (Se), Specificity (Sp) and Accuracy (Acc) are commonly used to evaluate the performance of retinal vessels segmentation, they are described as follows[1,2,5]:

\[
Se = \frac{TP}{TP + FN} \\
Sp = \frac{TN}{TN + FP} \\
Acc = \frac{TP + TN}{TP + TN + FP + FN}
\]

As the evaluation index mentioned above, the more we obtain the value of Se, Sp and Acc, the better performance we segment retinal vessels image.

4 Experimental Results and Analysis

In order to obtain better performance on retinal vessels segmentation, the fundus image needs to be pre-processed. Firstly, fundus image is transformed into gray-scale image, then image enhancing technique is adopted to improve the contrast of retinal vessel image, such as adaptive histogram equalization algorithm. As a result, the influence of uneven light, low contrast between retinal vessel and background is reduced. The effectiveness of five typical methods has been evaluated on DRIVE datasets, and results are shown in Fig.3 and Table 1.
(e) Matched filtering  (f) Mathematical morphology  (g) Tracking  (h) Deep learning

**Fig. 3** The retinal vessels segmentation results of five typical methods

| Segmentation Methods          | Evaluating Index |
|------------------------------|------------------|
|                              | Se   | Sp   | Acc  |
| Thresholding                 | 0.727 | 0.951 | 0.942 |
| Matched filtering            | 0.758 | 0.953 | 0.941 |
| Mathematical morphology      | 0.803 | 0.959 | 0.948 |
| Tracking                     | 0.745 | 0.946 | 0.937 |
| Deep learning                | 0.831 | 0.977 | 0.956 |

Table 1. Retinal vessel segmentation performance comparison of five typical methods

The segmenting method based on thresholding, matched filtering, mathematical morphology and tracking is a rule-based segmentation technology, they belong to the unsupervised retinal vessel image segmentation method. The unsupervised segmentation method is based on local intensity and gradient to establish segmentation model for unmarked image. The advantages and disadvantages will be evaluated, when the model is adjusted according to the minimization function to find the best separation between retinal vessels and the background. The method based on matched filtering is expensive in terms of time-consuming, the method based on tracking depends on much attention on selection of the initial seed point, and the method based on thresholding needs to iterate the threshold multiple times, so the efficiency is low. The segmentation method based on deep learning belongs to a supervised one. During training process, the corresponding vessel images are required to participate in training together. We can obtain a more accurate classification model by selecting more critical features from training image, taking them as vectors for training, so as to the accuracy and efficiency of retinal vessel segmenting are further improved. In summary, the unsupervised method has a faster segmentation speed and less computational complexity than the supervised one, but it is necessary to formulate judgment rules by itself. Due to the limitation by its applicability of rules, their segmenting effect is not ideal. As for accuracy, the result of supervised segmentation is generally better than the unsupervised method, but a large amount of prior data is needed for modeling during segmenting, and need more time-consuming.

**Conclusion**

Retinal vessel segmentation is an important project for fundus images research, it can effectively assist doctors to clinical diagnosis and treatment for cardiovascular diseases and ophthalmology diseases. In the paper, the significance of retinal vessels segmentation is presented at first, then five typical retinal vessels image segmentation methods are briefly introduced, that is thresholding, matched filtering, tracking, mathematical morphology and deep learning. We carry out experiments on the DRIVE public datasets and conduct performance evaluations to verify the segmentation performance. Among them, results on datasets show that method based on deep learning outperformed other approaches in terms of sensitivity and accuracy. Although many achievements have been made by researchers in this field, there is still have a room for improvement in retinal vessel segmentation technology. With the development of computer technology and continuous exploration in the field of deep learning, new theories will be applied in retinal vessels segmentation, the accuracy and efficiency will be further improved.
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