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An effective retinal blood vessel segmentation method using multi-scale line detection

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ABSTRACT

Changes in retinal blood vessel features are precursors of serious diseases such as cardiovascular disease and stroke. Therefore, analysis of retinal vascular features can assist in detecting these changes and allow the patient to take action while the disease is still in its early stages. Automation of this process would help to reduce the cost associated with trained graders and remove the issue of inconsistency introduced by manual grading. Among different retinal analysis tasks, retinal blood vessel extraction plays an extremely important role as it is the first essential step before any measurement can be made. In this paper, we present an effective method for automatically extracting blood vessels from colour retinal images. The proposed method is based on the fact that by changing the length of a basic line detector, line detectors at varying scales are achieved. To maintain the strength and eliminate the drawbacks of each individual line detector, the line responses at varying scales are linearly combined to produce the final segmentation for each retinal image. The performance of the proposed method was evaluated both quantitatively and qualitatively on three publicly available DRIVE, STARE, and REVIEW datasets. On DRIVE and STARE datasets, the proposed method achieves high local accuracy (a measure to assess the accuracy at regions around the vessels) while retaining comparable accuracy compared to other existing methods. Visual inspection on the segmentation results shows that the proposed method produces accurate segmentation on central reflex vessels while keeping close vessels well separated. On REVIEW dataset, the vessel width measurements obtained using the segmentations produced by the proposed method are highly accurate and close to the measurements provided by the experts. This has demonstrated the high segmentation accuracy of the proposed method and its applicability for automatic vascular calibre measurement. Other advantages of the proposed method include its efficiency with fast segmentation time, its simplicity and scalability to deal with high resolution retinal images.

1. Introduction

Changes in retinal vascular structures are manifestations of many systemic diseases such as diabetes, hypertension, cardiovascular disease and stroke. For example, changes in vessel calibre, branching angle or vessel tortuosity are results of hypertension [1,2]. The onset of neovascularization is a sign of diabetic retinopathy [3], a complication of diabetes which is the leading cause of blindness in developed countries. The presence of arteriovenous nicking is an important precursor of stroke [4,5]. The early detection of these changes is extremely important in order to perform early intervention and prevent the patients from major vision loss. To quantify these features for medical diagnosis, accurate vessel segmentation plays a critical role. Although many methods have been proposed, significant improvement is still a necessity due to the limitations in state-of-the-art methods, which include:

- poor segmentation in the presence of vessel central light reflex (i.e., bright strip along the centre of a vessel).
- poor segmentation at bifurcation and crossover regions.
- the merging of close vessels.
- the missing of small vessels.
- false vessel detection at the optic disk and pathological regions.

Among the problems mentioned above, the first three are most important due to their great impact on the quality of the vascular network obtained. For example:

- if central reflex pixels are not recognized as part of a vessel, the vessel may be misunderstood as two vessels.
- if two close vessels are merged together, they will be considered as one wide vessel.

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- poor segmentation such as the disconnection at vessel cross-over regions (where two vessels cross each other) will cause difficulties for the vessel tracking process.

These will lead to the inaccuracy in vascular network analysis such as the identification of individual vessel segments, vessel calibre measurement, or vascular abnormality (i.e., arteriovenous nicking) detection.

The segmentation results of some existing methods on a cropped retinal image with the presence of central reflex, close vessels and crossover points are shown in Fig. 1 to demonstrate the limitations of current approaches. Vessel disconnection is found in Staal et al. [6] result, while vessel merging is present in Soares et al. [7] result. Missing of central part of vessels due to vessel central reflex are found in both Staal and Soares et al. results. The problem with the segmentation produced by Ricci-line [8] method is the partial merging of two close vessels and the spurious segmentation at the crossover point. Even though the Ricci-svm [8] method produces accurate segmentation at these regions, it fails to detect small vessels.

The contribution of this paper is a novel segmentation method that is effective in dealing with the problems mentioned above. The underlying technique of the proposed method is a linear combination of line detectors at different scales to produce the vessel segmentation for each retinal image. A basic line detector uses a set of approximated rotated straight lines to detect the vessels at different angles. The difference between the average gray level of the winning line (the line with maximum average gray level) and the average gray level of the surrounding window provides a measure of 'vesselness' of each image pixel. The proposed method is based on an observation that by changing the length of the aligned lines, line detectors at different scales are achieved. Long length line detectors have shown to be effective in dealing with central reflex. However, we show later in this article that they tend to merge close vessels and produce false positives along the vessels. Short length line detectors have shown improvements of these situations but they introduce background noise in the image. In order to maintain the strength and eliminate the drawback of each individual line detector, line responses at different scales are linearly combined to produce the segmentation for each retinal image. Experimental results have shown that the proposed method is an attractive method for retinal vessel segmentation since:

- *it gives high segmentation accuracy especially at regions around the vessels*. This is reflected by the high local accuracy and the ability of the proposed method to provide accurate vessel width measurement.
- *it is an unsupervised method* which does not require the manual segmentation of vessels for training and the performance does not depend on the training set.
- *it is efficient with fast segmentation time*.
- *it can be easily extended to perform on high resolution retinal images*.

The segmentation result of the proposed method, which is shown in Fig. 1(f), has demonstrated the strengths mentioned above.

The rest of this paper is organized as follows. Section 2 provides an overview of state-of-the-art vessel segmentation methods. Details of the proposed method are described in Section 3. Section 4 presents the experimental results obtained on DRIVE and STARE datasets while the performance on REVIEW dataset is presented in Section 5. Finally, we conclude the paper with Section 6.

2. Related works

In response to the importance of the vessel segmentation problem, a large number of methods have been introduced in the literature.

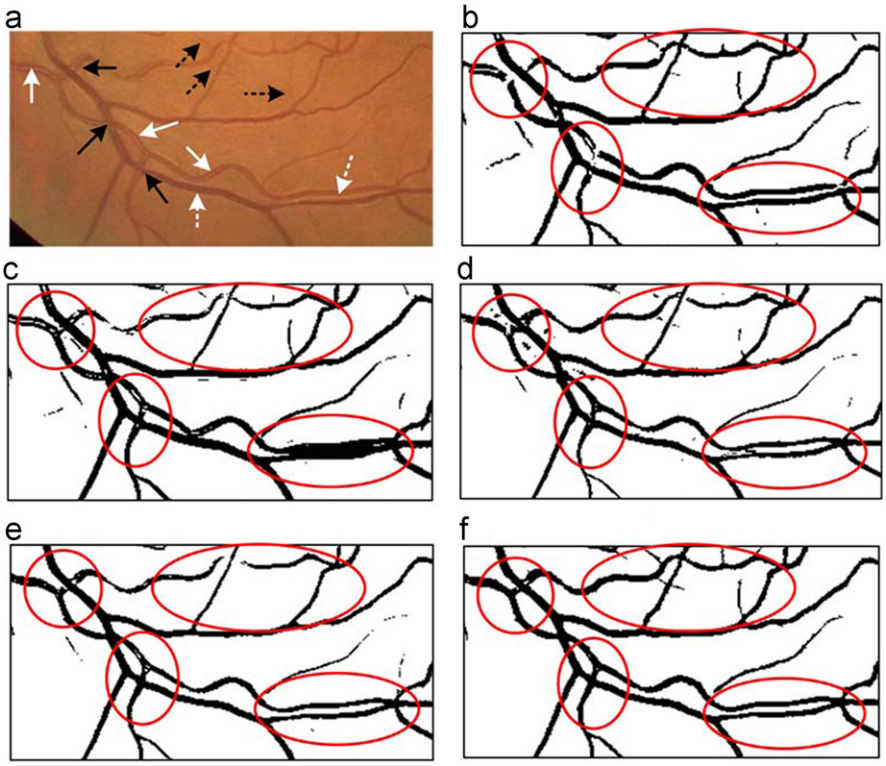

Fig. 1. Illustration of the limitations of existing methods: (a) a cropped retinal image shows the presence of vessel central light reflex (white solid arrows), close vessels (white dashed arrows), artery-vein crossing (black solid arrows), and small vessels (black dashed arrows) and segmentations obtained by (b) Staal et al. method [6]; (c) Soares et al. method [7]; (d) Ricci-line method [8]; (e) Ricci-svm method [8]; and (f) the proposed method. The segmentation result of the proposed method has demonstrated its effectiveness when providing accurate segmentation at the specified regions while being able to detect those small vessels.