Automated detection and classification of major retinal vessels for determination of diameter ratio of arteries and veins

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ABSTRACT

Abnormalities of retinal vasculatures can indicate health conditions in the body, such as the high blood pressure and diabetes. Providing automatically determined width ratio of arteries and veins (A/V ratio) on retinal fundus images may help physicians in the diagnosis of hypertensive retinopathy, which may cause blindness. The purpose of this study was to detect major retinal vessels and classify them into arteries and veins for the determination of A/V ratio. Images used in this study were obtained from DRIVE database, which consists of 20 cases each for training and testing vessel detection algorithms. Starting with the reference standard of vasculature segmentation provided in the database, major arteries and veins each in the upper and lower temporal regions were manually selected for establishing the gold standard. We applied the black top-hat transformation and double-ring filter to detect retinal blood vessels. From the extracted vessels, large vessels extending from the optic disc to temporal regions were selected as target vessels for calculation of A/V ratio. Image features were extracted from the vessel segments from quarter-disc to one disc diameter from the edge of optic discs. The target segments in the training cases were classified into arteries and veins by using the linear discriminant analysis, and the selected parameters were applied to those in the test cases. Out of 40 pairs, 30 pairs (75%) of arteries and veins in the 20 test cases were correctly classified. The result can be used for the automated calculation of A/V ratio.

Keywords: A/V ratio, retinal fundus images, computer-aided diagnosis, hypertensive retinopathy

1. INTRODUCTION

Ocular examination using retinal fundus images is relatively inexpensive, easily accessible study that is suitable for screening of eye diseases, such as glaucoma, diabetic retinopathy, and hypertensive retinopathy. However, ophthalmologists have limited time to look for a variety of abnormal signs on fundus photographs in a large number of cases. In order to improve diagnostic efficiency, we have been developing the computerized retinal fundus image analyzer, which includes the assessment of optic disc cupping[1, 2] and detection of retinal nerve fiber layer defect[3] for diagnosis of glaucoma, the detection of hemorrhages[4] and microaneurysms[5] for diagnosis of diabetic retinopathy, and the detection of retinal blood vessels and calculation of diameter ratio of arteries and veins (A/V ratio)[6] for diagnosis of hypertensive retinopathy.

One of the signs of hypertension that can be found on retinal fundus images is arteriolar narrowing. The arteriolar narrowing is often assessed by measuring the A/V ratio in pairs of large vessels running side by side and at a certain distance from the optic nerve head, e.g., from half-disc to one disc diameter from the optic disc margin[7] in the U.S. and from quarter-disc to one disc diameter from the optic disc margin in Japan. However, such measurement is seldom done systematically and quantitatively, making the consistent evaluation difficult. Therefore, automated calculation of A/V ratio in retinal fundus images can be useful to ophthalmologists in the detection of arteriolar narrowing and longitudinal evaluation of vasculature conditions.

Many groups have been investigating automated methods for segmentation of retinal blood vessels, which include, but not limited to, the methods using differential filters[8-10], matched filters[11-13], line detection operators[14-16], Gabor wavelets[17, 18], active contour methods[19, 20], and clustering method[21]. For determination of A/V ratio, Pakter *et al.* investigated a semi-

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automated method to calculate vessel widths and found that the A/V ratio measured by their method was inversely associated with systolic blood pressure[22]. Their method requires the manual identification of vessel axis. A semi-automatic method proposed by Tramontan *et al.* consists of tracing of retinal vessel network by means of a fuzzy c-means classifier, discriminating arteries and veins on the basis of the central reflex which is more prominent in arteries than veins, and estimating A/V ratio[23]. However, in our experience, the central reflex is not always apparent. Nam *et al.* investigated an automated method for measuring A/V ratio by obtaining an intensity profile around an optic disc[24]. Based on the characteristics of the valleys in the profile, which correspond to potential vessels, they were classified into arteries and veins. Niemeijer et al. proposed a method for classifying retinal vessels into arteries and veins using image features and k-nearest neighbor classifier[25]. As a preliminary investigation, they employed the manual vessel segmentation result and determined their image features. In this study, we propose computerized methods for detecting retinal blood vessels, selecting major vessel segments, and classifying them into arteries and veins.

2. IMAGE DATABASE

Retinal fundus images used in this study were obtained from the Digital Retinal Images for Vessel Extraction (DRIVE) database, which is available to researchers for the purpose of comparative evaluation of retinal vessel segmentation schemes[8, 26]. The database includes 40 retinal fundus images that were obtained from a diabetic retinopathy screening program in the Netherlands and are equally divided into training and testing sets. The images were saved in JPEG format with 565 x 584 pixels. For each image, manual segmentation result for blood vessels is provided as a reference standard. Based on the reference standard, an ophthalmologist selected two pairs of major arteries and veins running from the optic disc to the upper and lower temporal region which may be used for the measurement of A/V ratio: they became the gold standard for this study. Figure 1 shows a retinal fundus image with two pairs of major vessels that were selected.

Figure 1. Retinal fundus image with two pairs of major arteries and veins that may be used for the measurement of A/V ratio. The darker lines correspond to arteries, and the brighter lines correspond to veins.

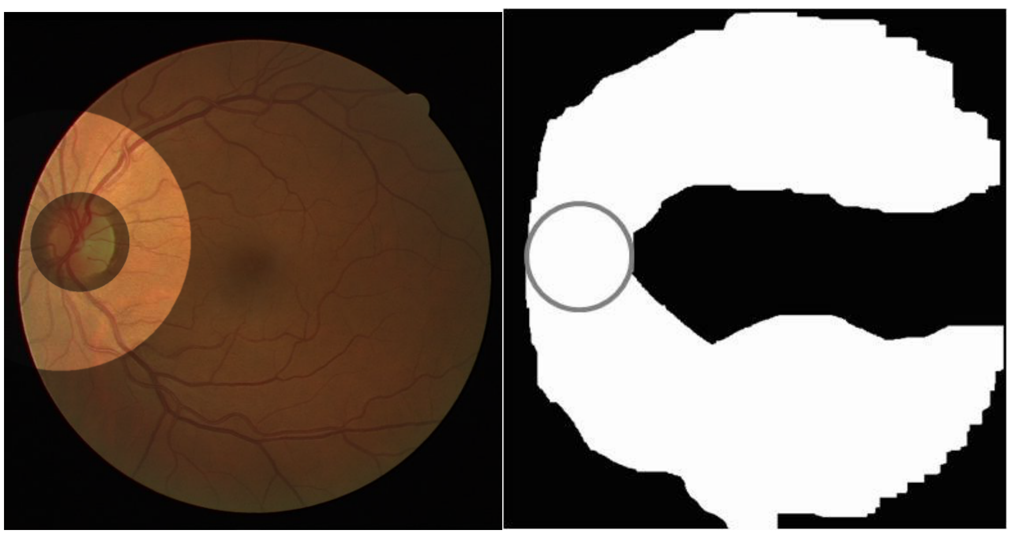
3. METHODOLOGY

3.1 Vessel segmentation

First, retinal blood vessels were extracted on the basis of the contrast in the green channel of the RGB images. In our previous studies, two independent schemes were developed for the segmentation of the retinal blood vessels. In this study, we combined the two methods. For the analysis of optic disc for glaucoma[1, 2], retinal blood vessels were automatically extracted using the black top-hat transformation[27]. The structure element used for the top-hat transformation was a circle with the diameter approximately equal to the diameter of the thickest vessel, which was determined to be 11 pixels. For the detection of hemorrhages and microaneurysms[4, 5], vessels were segmented using the double ring filter. The double ring filter is structured as a circle, which diameter corresponds to that of the thickest vessel, with the outer ring. The pixel values of a filtered image correspond to the differences in average pixel values in the circle and the ring regions. In this study, the outputs from two operations were summed, and vessel regions were determined by applying a threshold.

3.2 Classification of arteries and veins

Japanese guideline for reading retinal fundus images for hypertension states that the A/V ratio should be measured on vessels in the region from quarter-disc to one disc diameter from the optic disc margin as shown in Fig. 2(a). In addition, the major vessels used for the A/V ratio measurement usually run from an optic disc to the upper and lower temporal regions. In order to select such vessels, a vessel-range mask was superimposed to the images for including vessels that were inside this mask. The vessel-range mask was created based on the gold standard vessels in the training cases by centering the optic discs as shown in Fig. 2(b). The vessel classification method was applied to only those vessels in these regions. In this study, the optic disc regions were determined manually; however, it can be replaced by the automated method in the future. Because A/V ratio is usually measured on large vessels, thin vessels with diameters less than two pixels were removed. The remained vessels were partitioned to vessel segments by detecting bifurcations and vessel crossings.



(a) (b)

Figure 2. (a) The region quarter-disc to one disc diameter from the optic disc margin, in which A/V ratios would be measured. (b) The range of the major vessel locations determined by superimposing the optic disc centers of the 20 training cases. A circle specifies the approximate location of optic discs.

Ophthalmologists may distinguish arteries and veins on the basis of the color and width of the vessels. The retinal arteries normally appear brighter and slightly thinner than veins. Because the vessel widths would be strongly influenced by the vessel segmentation result, in this study, we used the color information for the classification of arteries and veins; in the future, the width information may be included. The difference in color between the arteries and veins is more prominent near the center of the vessels. Therefore, the centerline pixels of the remained vessel segments were identified, and their pixel values in three color channels were used as the image features. Each centerline pixels were classified to those belonging to the arteries and veins using the linear discriminant analysis (LDA). The LDA was trained using the gold standard centerline pixels in the training cases. Based on the result of LDA, the vessel segments were determined to be arteries or veins by the majority rule, i.e., if the number of centerline pixels that were classified to arteries is larger

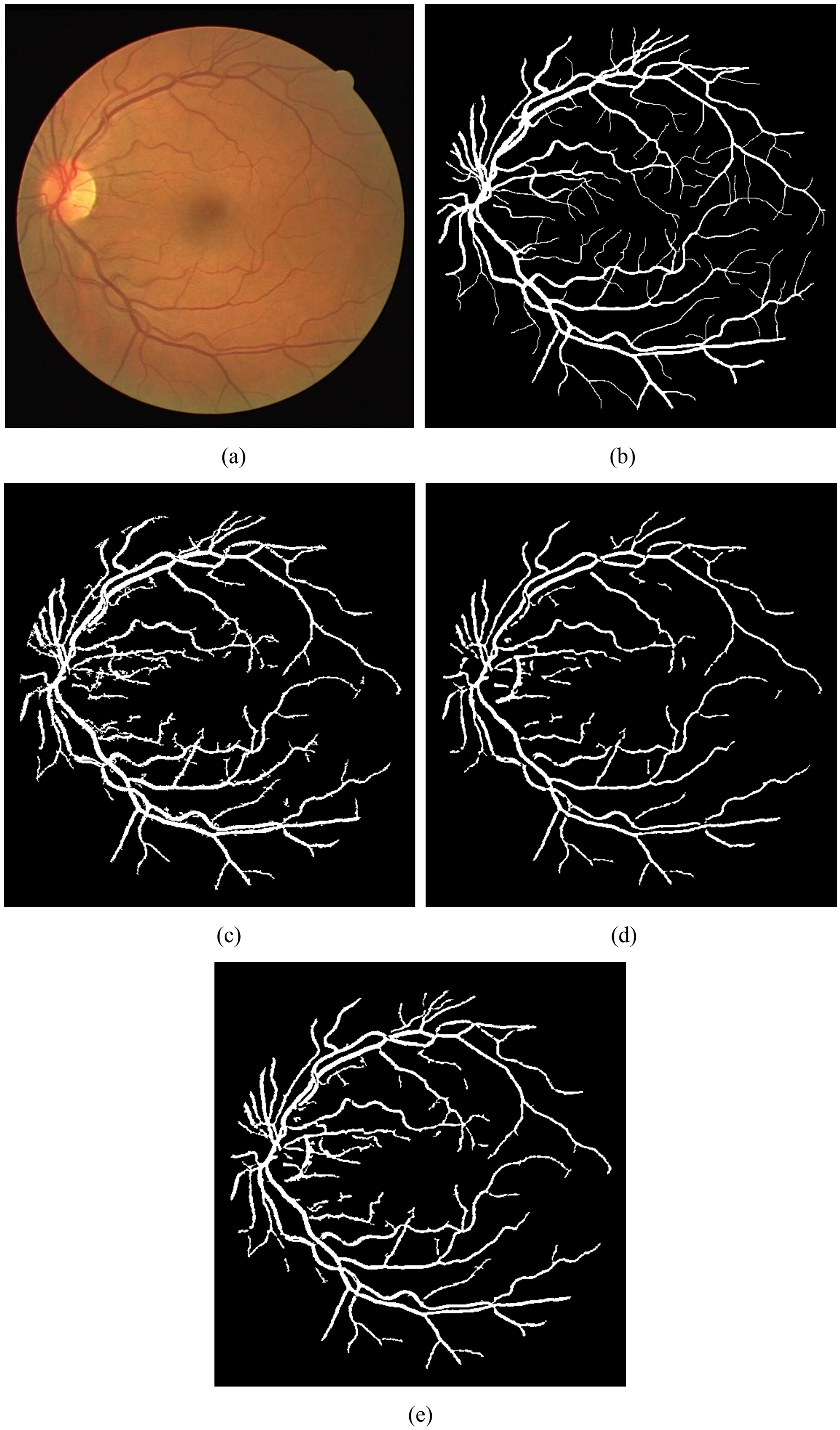


Figure 3. Retinal blood vessel segmentation results. (a) The original image (b) gold standard vessels (c) vessels extracted by the black top-hat transformation (d) vessels extracted by the double ring filter (e) vessels extracted by the combined method.

than that of those classified to veins, the entire segment was determined as an artery. Finally, any inconsistencies were corrected on the basis of the bifurcation and vessel crossing information.

The A/V ratios are often measured on pairs of major vessels running parallel to each other. However, other vessels were still remained. Using the result of LDA, pairs of arteries and veins that were located side by side were selected, and other small vessels and vessel segments, such as those diverged from the major vessels, were removed. If there were more than two vessels running parallel, an artery and a vein with the largest diameters were selected. The result was evaluated based on the number of paired vessels out of 40 pairs (two pairs each in the 20 test cases) that were classified correctly.

4. RESULTS AND DISCUSSION

4.1 Vessel segmentation

For extracting the blood vessel regions, the methods using the black top-hat transformation and double ring filter have advantages and disadvantages. The vessel segmentation results using two methods are shown in Fig. 3(c) and 3(d). It is apparent that the vessel walls segmented using the black top-hat transformation were uneven, and the method tends to overestimate the vessel regions. On the other hand, the method using the double ring filter tends to underestimate the blood vessel regions. By combining the two methods, the result was improved as shown in Fig. 3(e). Table 1 summarizes the results by three methods. The true positive fraction is defined as the ratio of the number of pixels that were segmented correctly to the number of pixels in the gold standard vessels. The overestimation fraction is defined as the ratio of the number of pixels that were incorrectly segmented to the number of pixels in the gold standard vessels. Although some minute vessels were not extracted by the proposed method, detection of such thin vessels is not required for the measurement of the A/V ratio. In this study, two previously developed methods were combined by simply taking the average of the outputs. The best way to combine two methods for the purpose of determining A/V ratio should be investigated further in the future.

Table 1. Results of retinal blood vessel segmentation using three methods.

Segmentation method	True positive fraction	Overestimation fraction
Black top-hat transformation	0.806	0.539
Double ring filter	0.683	0.210
Combined method	0.793	0.410

4.2 Classification of arteries and veins

After thin vessels and vessels outside the regions of interest specified in Fig. 2 were removed, the centerline pixels of the remained vessels were classified by LDA. The classification accuracy in terms of the fraction of the centerline pixels that were classified correctly as belonging to arteries and veins was 88.2%. However, after selecting the pair of major artery and vein each in the upper and lower temporal regions, the vessel recognition accuracy in terms of the fraction of paired vessels that were selected correctly was 75% (30/40 pairs). One of the reasons for misrecognition was that some arteries were not segmented accurately because of their low contrast. When the vessel segmentation result is further improved, the classification and recognition of paired vessels may also be improved. Figure 4 shows the images with pairs of major arteries and veins that were recognized correctly. The dark grey lines correspond to the arteries, whereas the light grey lines correspond to the veins. Using these results, the A/V ratios can be measured.

5. CONCLUSION

We investigated the computerized method to automatically detect major retinal blood vessels and classify them into arteries and veins for the measurement of A/V ratio. Using the proposed method, 30 out of 40 pairs of arteries and veins in 20 test cases were correctly determined. The method can be useful for automatic measurement of A/V ratio in the evaluation of hypertension on retinal fundus images.

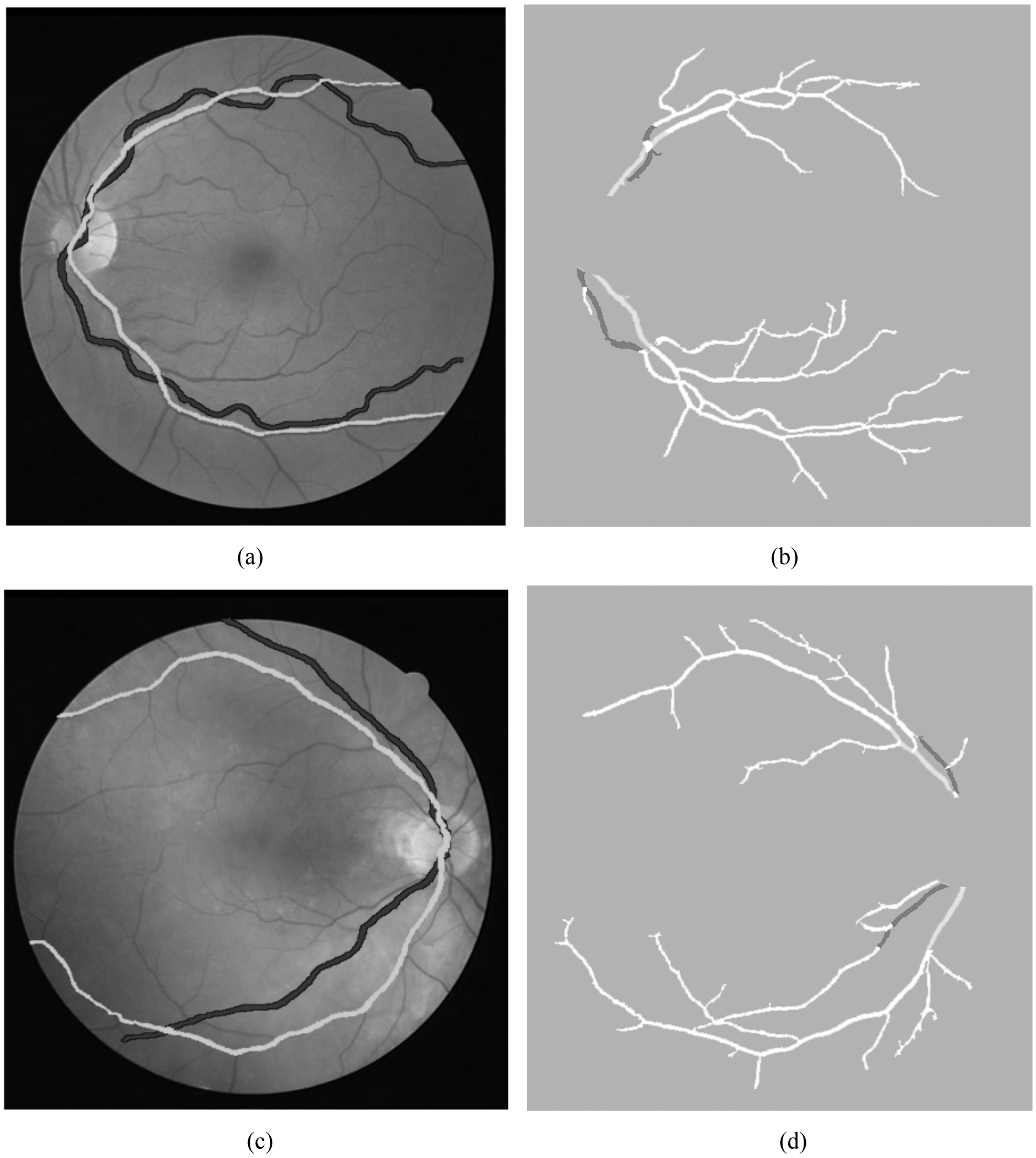


Figure 4. Retinal blood vessel classification results. (a) The original image with the gold standard vessel pairs (b) vessel classification result for (a). (c) The original image with the gold standard vessel pairs (d) vessel classification result for (c).

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