Detection and Estimation of Diameter of Retinal Vessels

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Abstract. The change in retinal vessel diameter is a crucial measure of disorders, including hypertension, high blood pressure, and diabetes. Abnormalities in the retinal vasculatures can signify a spectrum of diseases. In retinal fundus images, providing an automatically estimated diameter of blood vessels may aid clinicians in diagnosing diseases like hypertensive retinopathy, which can even lead to blindness. Therefore, automated diagnosis of these diseases requires accurate measurements of vascular diameters. In this research work, this paper have investigated three methods for the estimation of the diameter of the retinal blood vessel. Two publicly available datasets such as Central Light Reflex Image Set (CLRIS) and Vascular Disease Image Set (VDIS) of The Retinal Vessel Image Set for Estimation of Width (REVIEW) database have been used for the comparison of estimated diameter of the retinal vessel. The performance of these three algorithms is compared against the available ground truth average diameter for both CLRIS and VDIS. It was found that the estimated diameter is closer to the available ground truth using morphological-based and center line-based, respectively. However, the estimated diameter using the line integral-based method is significantly different from the ground truth for both datasets.

Keywords: Retinal Vessel · Diameter Estimation · Image Segmentation · Fundus image

1 Introduction

Retinal vessels are the only component of the central circulation that can be closely examined and directly visualized. Various disorders cause retinal vessels to undergo various morphological changes. The diameter of the retinal vessel is one of the morphological changes. It is believed that changes in retinal vascular diameter inside the fundus are a reasonable indicator of the risk of diabetic retinopathy. The accurate measurement of the diameter of the retinal vessels can help us with the diagnosis. Vascular diameter measurement and vessel segmentation are both crucial and challenging technical tasks that must be accomplished by any system attempting to automate the diagnosis of vascular disorders.

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In literature, several methods are suggested to segment the vascular network. In this work, this study have used Otsu method, which is a well-known method for image segmentation. Morphological (MO) [1], Center Line (CL) [2], and Line Integral (LI) [3] are methods for the estimation of diameter of retinal vessels in literature. This paper presents a comparison of three techniques for measuring vascular diameter of 2-D retinal image. Kawasaki et al. [4] revealed that retinal artery narrowing and retinopathy are associated with an increased risk of stroke in people without diabetes. After Long-Term Follow-Up in the Rotterdam Cohort Study, any stroke was shown to be substantially correlated with the retinal vascular diameter [5].

Salwan et al. [6] developed a concept for measuring vessel diameter using fundus images. In this, two lengths of plastic tubing with known diameters were infused via blood and photographed. These presumptively have blood column widths of 8–35% and 7–48%. With more precise measurement of diameter on all profiles and the kick points in vessel width, they came to the conclusion that the vessel width can be measured.

Wong et al. [7] introduce a technique for measuring vessel width that identifies the fundus associated with abnormalities of micro vascular retinal vessels. The presence and severity of arteriolar inner retinal tightness as well as another microvascular distinctness are identified using original computer-connected imaging techniques.

N. Chapman et al. [8] introduced a technique for measuring blood artery width based on arterial diameters obtained from the branch points that maintains a constant shear stress in arterial networks.

Other methods for measuring retinal diameter suggested in literature are based on different image processing ideas, such as the graph-theoretic method [9], adaptive Higuchi's dimension [10], mask creation [11] and multi-step regression method [12].

2 Methodology

2.1 Estimation of Diameter of Retinal Vessel Based on Morphological Operation

It is a computer-aided technique for measuring the retinal blood vessel diameter. This method is evaluated on the VDIS and CLRIS of the REVIEW [13] dataset. The images of VDIS and CLRIS are considered for this experiment. In preprocessing, this paper have considered only the green channel of the retinal image as the blood vessels have better contrast in the green channel than the red and blue channels (see Fig. 1). A part of the retinal image is captured to obtain the region of interest, as mentioned in the description of the dataset.

Segmentation and Extraction of Region of Interest. The ROI detection begins with selecting the vessel whose diameter needs to be estimated. Once the ROI is captured, as shown in Fig. 1 then, it is segmented by Otsu's approach, which determines the threshold value in such a way that has minimum intra-class variance. After the ROI is segmented, morphological operation such as opening is applied to reduce the effect of noise.

Calculating the Euclidian Distance Transform. Distance transform determines the distance between each pixel in a binary image and all the white neighboring pixels. Let's say X and Y are two distinct pixels that reside in an image space, with X coordinate being

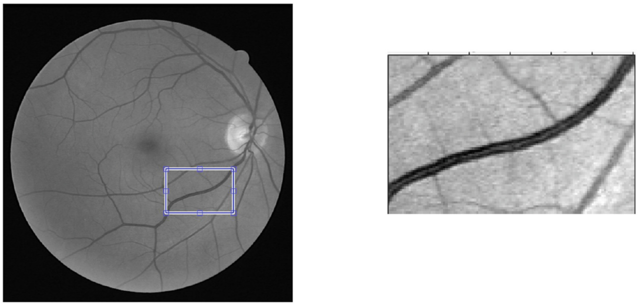


Fig. 1. Cropping the ROI from the original image.

(X_c,X_d) and Y coordinate being (Y_c,Y_d). The Euclidean distance (ED) between X and Y is calculated as:

$$D(X, Y) = \sqrt{((X_c - Y_c)^2 + (X_d - Y_d)^2)} \tag{1}$$

ED technique applied to the obtained binary image. Figure 2(a) shows the extracted ROI Euclidean distance. The center line shown in Fig. 2(b), represents the ED intensity along the boundary from each location. In the ED technique, each binary image pixel is provided a number that indicates the separation between that pixel and the closest white pixel in that image.

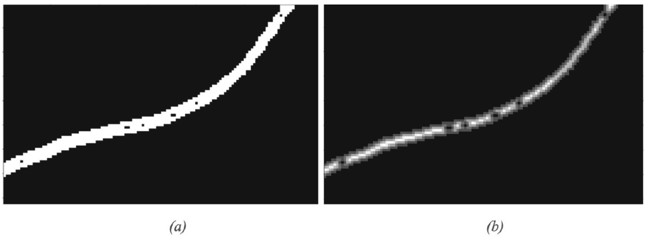


Fig. 2. (a) ROI of binary image, (b) EDT

Skeletonise the ROI. In order to identify the blood vessel centerline, this method uses the morphological thinning operation [14] to skeletonize the extracted ROI. The thinning process iteratively lowered the object pixels in the boundary region of the ROI. The thinning procedure keeps important ROI pixel information during the object pixels reduction. If it is unable to narrow the ROI.

further, then an iterative thinning procedure is terminated. Once thinning has been halted, the ROI skeleton is estimated by counting the available pixels. The skeletonization of ROI is shown in Fig. 3(b).

The thinning method offers a few essential features, such as maintaining the object characteristics and maintaining the original object topology, which is necessary for classifying data, extracting features, identifying objects, and creating a one-pixel width skeleton.

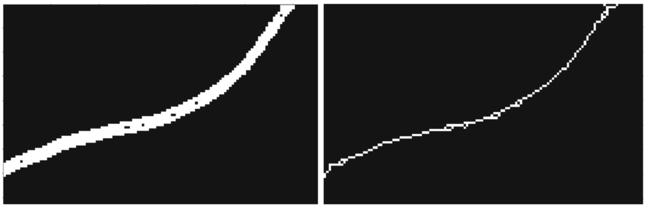


Fig. 3. (a) ROI of binary image (b) ROI skeletonization

For exact quantification of vessel diameter, it is essential to skeletonize the ROI such that its centerline is of one row.

Vessel Diameter Quantification. Finally, the radius of ROI is determined using its center line and the mean ED between several white pixels located along the border. Using the average value of the radius, the mean diameter of the ROI is calculated. Let $Q_1, Q_2, Q_3, \ldots, Q_n$ be the white pixel at the extracted ROI edge and $P_1, P_2, P_3, \ldots, P_n$ be the white pixel on the center line of ROI, and here, 'n' stands for total number of pixel pairs. The coordinates for $Q_1, Q_2, Q_3, andQ_n$ pixels are (X_{q1}, Y_{q1}), (X_{q2}, Y_{q2}), and (X_{qn}, Y_{qn}), and the coordinates for P_1, P_2 and P_n pixels are (X_{p1}, Y_{p1}), (X_{p2}, Y_{p2}), and (X_{pn}, Y_{pn}). Following that, the mean of ED and the ROI radius can be calculated as:

$$MeanED = \frac{\sum_{i=1}^{n} \sqrt{((X_{qi} - X_{pi})^2 + (Y_{qi} - Y_{pi})^2)}}{n} \tag{2}$$

Here, "n" stands for the total number of points used for computing its radius. Finally, the mean diameter value is calculated by simply multiplying it by 2 as:

$$MeanDiameter = 2 * MeanRadius \tag{3}$$

2.2 Diameter Calculation Based on Center Line

Diameter Calculation of Vessels. The distribution of gray levels in the direction of vascular diameter in the typical retinal image can be seen as an inverted Gaussian model shown in the Fig. 4. This method takes 'k' as the vertical dimension between vessel center line and pixel, σ_1 is the vessel diameter span, while $g(k)$ is the pixel gray value. The function of the gray value distribution is given by

$$g(k) = -\exp\left(\frac{-k^2}{2\sigma_1}\right)^2, \quad g(k) = g(-k) \tag{4}$$

Extraction of Initial Center Points. This method selects an area of the retinal image that contains the interesting vascular region, as shown in Fig. 1, and computes the center points. In order to determine the center points of the vessel, this method uses the

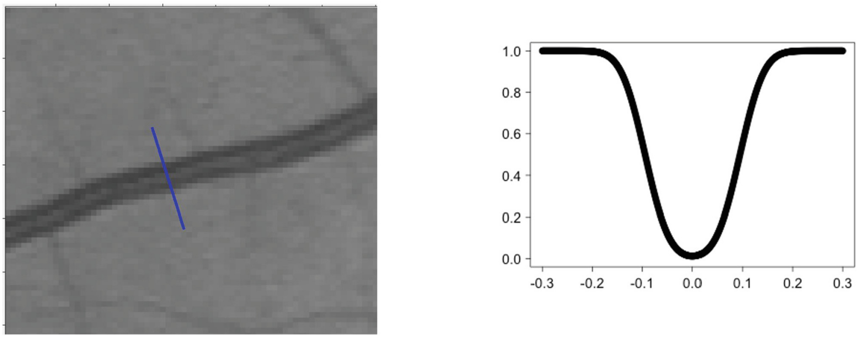


Fig. 4. Up-side down Vessel Gaussian model

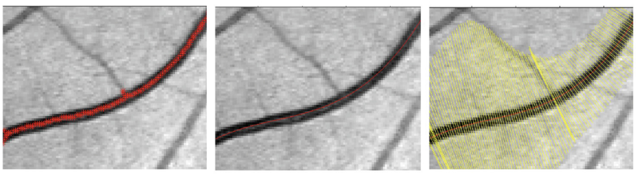
morphological thinning operation to skeletonize the extracted ROI. After extracting the center pixel of the vessel, this method will find the x and y coordinates of the center pixel of the vessel and then plot it into an image as shown in Fig. 5(a).

Vascular Center Points with Polynomial Fitting. In this research work [2], a three-order polynomial fitting is employed on center points to compute the vascular center line and its vertical line to account for different vascular morphologies. The three-order polynomial fitting equation is given as:

$$y = a_0.x^3 + a_1.x^2 + a_2.x + a_3 \tag{5}$$

By solving the equation, one may get the value of the coefficients of the polynomials $[a_0, a_1, a_2, a_3]$ and then compute the derivative to obtain the tangential equation of the center line. The vertical line as shown in Fig. 5(c).

Measuring the Diameter Along a Vertical Line. It is challenging to locate the exact intersection point of the vertical line, and vascular wall as no precise threshold can separate the vessels from the background in a gray-level image. The research work [2] employed a segmented image to overcome this problem. Firstly, ROI is captured in a monochrome image of the same size as the grey level vessel, then the center line and vertical line are created for diameter calculation. Figure 6 shows the segmented vessel and vertical lines.



a) b) c)

Fig. 5. a) Center points b) Polynomial fitting c) Vertical lines

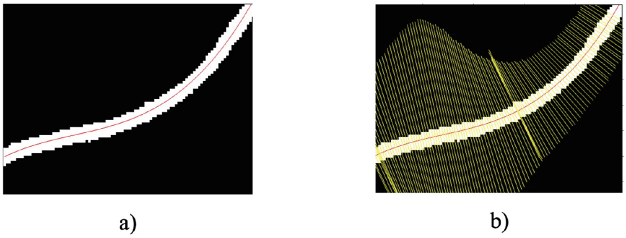


Fig. 6. a) Vessel Segmentation. b) Vertical lines (Color figure online)

Now, to extract the diameter of the vessel, this method takes the (X, Y) coordinates of all the yellow vertical lines, then the pixel value at each yellow line is calculated. It is considered that the coordinate of the first pixel of the yellow line, which has pixel value one as (a_1, b_1) and the last one as (a_2, b_2), the shortest distance between these two coordinates of every yellow line is the diameter of vessel and the shortest distance between these two coordinates of every yellow line is calculated as:

$$d = \sqrt{(a_2 - a_1)^2 + (b_2 - b_1)^2} \tag{6}$$

2.3 Measurement of Retinal Vessel Thickness Based on Minimum Line Integrals

This method is based on an intuitive technique for determining an object's thickness. The simple approach to assess its local thickness is to place two fingers on either side of an item, and then change the angle of the section connecting the fingertips locally (similar to doing so), as long as there is a minimum Euclidean distance between them. This distance is then used to calculate the object's local thickness. Therefore, this method can be pose as solving a restricted optimization problem, which is minimizing the distance in a particular region.

However, in this approach, the area is identified by exactly the point where one would like to define the thickness. As a result, the limitation is that the point must be on the line segment joining the two fingertips. For this, this paper may consider only those line segments that pass through the point where one is interested to determine the thickness. In this case, several lines are drawn using line integral passing through the selected point. The shortest of them is taken as the thickness of the vessel at that point.

Measurement of Vessel Diameter. This paper compute each line integral centered at each pixel point, starting from the point of interest and continuing in each of the two opposite directions separately. Once all the line integrals have been calculated (i.e., in all the possible directions, Fig. 7(a)), the minimum amongst them is taken as the diameter at that point (Fig. 7(b)). To reduce the impact of noise, one choice would be to take into account the average of some of the smallest integrals.

For this experiment, this paper take the point of interest, and the line integrals are computed in all directions at a step angle of 15°. Then, a scan is performed in all directions until the edge of the vessel intersects with all the line integrals (Fig. 7(b)), and various intersecting points are obtained. The length of all the line integrals is measured and out of all, the line integral with the minimum length is considered as the thickness of the vessel (Fig. 7(c)).

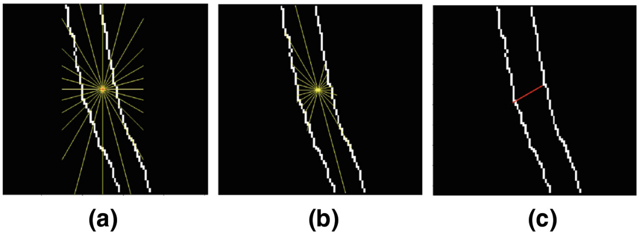


Fig. 7. (A) Line integrals, (b) Vessel intersect with edge, (c) Thickness of vessel

3 Result and Discussion

The diameter of ROI is determined using 30 different segments from CLRIS [13] images and 75 different segments from VDIS [13] images. The manually diameter estimated on these two datasets from 3 independent observers is available. This paper compute the mean diameter of each vessel of the two datasets and compare with the mean of the diameters computed by three different independent observers. Tables 1 provide the mean vessel diameters determined for VDIS and CLRIS [13] datasets.

The output of the existing algorithms, along with manually gathered REVIEW results, are illustrated and compared in Table 1. The name of algorithms is listed in column 2 of Table 1, and the relative percentage difference with respect to average of the observers is shown in column 5. The mean diameter and standard deviation (SD) in pixels utilized for the performance evaluation are provided in columns 3, and 4 of Table 1, respectively.

It can be seen that in the case of CLRIS images, the center line method is performing better as compared to the morphological and line integral methods. The morphological approach gives minimum absolute relative percentage difference w.r.t. average of the observers and the line integral method gives maximum absolute relative percentage difference w.r.t. average of the observers.

In the case of VDIS images, the centre line method performs better than the morphological method and line integral method. The centre line method gives minimum absolute relative percentage difference w.r.t. average of the observers and the line integral method gives maximum absolute relative percentage difference w.r.t. average of the observers.

The results obtained from morphological operation-based method and center line method is close to the manually calculated mean diameter. Therefore, these methods can be seen as potential methods in the application of the diagnostic system of modern ophthalmology that can predict cardiovascular and retinal diseases.

Table 1. Comparison of the diameter obtained with the existing methods and manual measurement

Dataset	Method	Mean Diameter	SD	Absolute relative percentage difference w.r.t average of the observers
CLRIS	Average of the observers	13.8	4.12	–
	Center line	**13.02**	3.91	**5.65%**
	Morphological	12.79	3.92	7.31%
	Line integral	15.33	2.05	11.08%
VDIS	Average of the observers	8.85	2.57	–
	Center line	8.25	1.65	6.77%
	Morphological	**8.33**	1.3	**5.87%**
	Line integral	10.69	1.66	20.79%

4 Conclusion and Future Direction

The measurement of diameter of retinal vessels plays an important role in the structured analysis of the retina and are potentially valuable for the automated diagnosis of eye diseases such as arteriosclerosis and diabetic retinopathy. This paper have investigated three existing methods such as (i) morphological-based, (ii) Centre line-based and (iii) line integral-based to estimate diameter of retinal vessels. The performance of these three methods is compared with the available ground truth diameter on two publicly available datasets such as CLRIS [13] and VDIS [13].

The results obtained from the morphological and center line-based methods showed that these approaches are reliable and consistent in estimating the blood vessel diameter from retinal images. The performance of line integral based method was found to be inferior among the three methods investigated to estimate the diameter of vessel.

As a part of future work, this study seeks to identify vascular bifurcation, branching and crossover points in retinal images. It helps to predict many heart diseases and can be also be used for image registration and biometric features.

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