Simple and Efficient Method to Measure Vessel Tortuosity

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***Abstract*— Retinal vessels tortuosity is one of the important signs of cardiovascular diseases such as diabetic retinopathy and hypertension. In this paper we present a simple and efficient algorithm to measure the grade of tortuosity in retinal images. This algorithm consists of four main steps,vessel detection, extracting vascular skeleton via thinning, detection of vessel crossovers and bifurcations and finally calculating local and global tortuosity. The last stage is based on a circular mask that is put on every skeleton point of retinal vessels. While the skeleton of vessel splits the circle in each position, the local tortuosity is considered to be the bigger to smaller area ratio. The proposed algorithm is tested over the Grisan's dataset and our local dataset that prepared by Khatam-Al-Anbia hospital. The results show the Spearman correlation coefficient of over than 85% and 95% for these two datasets, respectively.**

Keywords-hypertensive, retinopathy, vessel, tortuosity, image processing

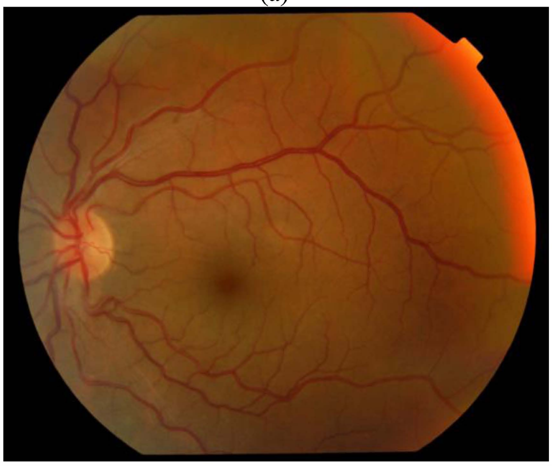
I. INTRODUCTION

Diabetic retinopathy (DR) disease is the main cause of blindness in the world. Early detection of DR can significantly help medications to be more effective and may slow the progress of the disease. Retinal vascular tortuosity is considered to be one of the important signs for diagnosing the mentioned disease. Fig. 1 shows the tortuous and non-tortuous retinal vessels.Measuring this sign can be very time consuming if it is to be subjective. Therefore by automating the quantification of this property, controlling the progress of the disease can be much easier.

Several techniques have been proposed to grade vessel tortuosity in retinal images. Hart et al. [1] employed some techniques based on integration over power of curvature for center line of vessels. They showed that the squared curvature presents nearest results to the ophthalmologists' notion. One of the methods widely used for tortuosity measurement is curve length over chord length ratio [2,3]. The main drawback of this method is where there is two vessels with same chord length and curve length but differ in number of curves. To overcome this problem, Grisan et al. [4] partition each vessel in segments with constant sign of curvature. They measured the tortuosity of each segment based on curve length over chord length ratio and combined them as tortuosity density. Tracco et al. [5] presented a similar measure, but they claimed that perceived tortuosity is increased with thickness of the vessels. So, instead of using vessel centerline, they combined curvatures of both sides of the vessels. Ghadiri et al. [6-7] proposed two other techniques based on circular Hough transform and non-subsampled Contourlet transform.

In this paper we present a simple and efficient algorithm for evaluation of tortuosity in retinal images. The next section describes this algorithm. Section III presents the experimental results to evaluate the algorithm and finally, section IV contains conclusions.

(a)



(b)

Figure 1. Vessel tortuosity in retina. Image (a) shows a normal tortuosity, whereas image (b) shows a high tortuosity.

II. THE PROPOSED ALGORITHM

All the different algorithms that have already been introduced for evaluating the tortuosity are used semi-automatically such that the user should select one of the vessels first and the algorithm will then calculate and present an evaluation for its tortuosity. However, if a machine is meant to be considered as an automatic diagnosis tool for detecting tortuosity in vessels, the mentioned algorithms will not be helpful for sure as they need interaction with the user. From this perspective, the article ahead introduces an algorithm and while comparing it with the recently proposed algorithms, it will be also evaluated in automatic situations.

The main steps of the proposed algorithm are as follows:

- Vessel detection,
- Extracting vascular skeleton via thinning,
- Detecting vessel crossovers and bifurcations,
- Calculating local and global tortuosity

In the following, each of these steps will be explained in detail.

A. Vessel Detection

The vessel detection algorithm used here is based on Local Radon Transform algorithm presented in [8]. At first, while vessels have the most contrast in a green plane, this plane is extracted from the RGB image. Then, the image is divided into some overlapping areas and after putting a circular mask on each part, the Radon Transform is calculated. After finding the maximum result, the degree in which this maximum has occurred shows the direction perpendicular to the vessel in the sinogram. By scrutinizing the calculated degree in the sinogram, first the existence of a vessel is checked and if this existence is approved then a local linear approximation for the vessel segment is determined. By combining local information, the vascular network of the entire image is obtained. Fig 2 shows the result of applying vessel detection algorithm on Fig 1.b. As the Radon Transform is a smoothing transform, the vessel detection algorithm can perfectly find an acceptable result even in the presence of noise.

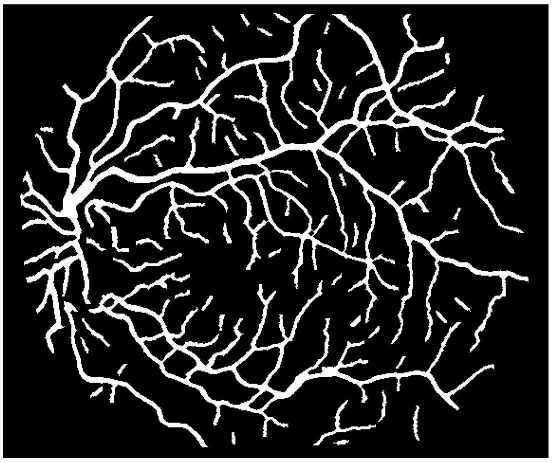


Figure 2. Result of vessel detection algorithm over the Fig. 1.b

B. Extracting Vascular Skeleton via Thinning

For evaluating vessel tortuosity in the proposed algorithm, extracting vascular structure is necessary. For this reason, morphologic thinning algorithm is used. Thinning operation is performed based on Guo et al. method.

C. Detecting Vessel Crossovers and Bifurcations

Since evaluating tortuosity is failed on vessel crossovers and bifurcations, before determining the tortuosity, crossover and bifurcation segments are recognized and then will be eliminated from the vascular skeleton. For this reason, the algorithm draws a circle in every point of the vascular skeleton and then the hit areas of the circle with the structure will be counted (n). n=3 and n=4 show bifurcation and crossover in the specified segments of the skeleton, respectively. These segments will be eliminated from the vascular skeleton. Fig 3 shows the result of extracting the skeleton, crossover and bifurcation segments for Fig 2.

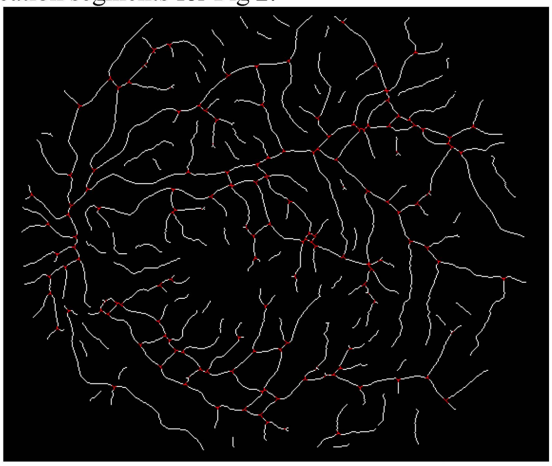


Figure 3. Result of thining algorithm over the Fig. 2 and detection of Crossovers and Bifurcations. The Crossovers and Bifurcations are shown by red color.

D. Calculating Local and Global Tortuosity

Computation of vessel tortuosity is based on curvature estimation. Curvature of the curve $y = f(x)$ is calculated by the following equation,

$$\kappa = \frac{y''}{(1+y'^2)^{3/2}} \qquad (1)$$

in which y' and y'' are the first and the second order derivations of y, respectively.

Estimating the curvature for a discrete signal is an ill-posed problem. For this estimation in a discrete image signal, different algorithms have been proposed. One of them is Frette et al. [10] algorithm. In this algorithm,for calculating the curvature in every point of the curve, a circle with a center at the specified point and of radius b is drawn and by using the following equation the curvature is estimated.

$$\kappa_1 \approx \frac{3\pi}{b}\left(\frac{A}{A_{tot}} - \frac{1}{2}\right) \qquad (2)$$

where, A and A_{tot} in the equation are the gray area and the total area of the circle in Fig 4, respectively.

In the absence of any curvature, the above equation gives zero as the result. An alteration which is made to it is that the curvature is estimated using the following equation.

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$$\kappa_2 \approx \frac{A}{A_{tot} - A} \tag{3}$$

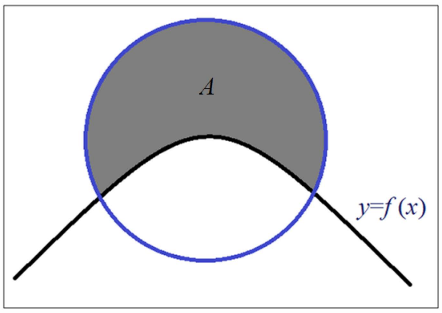

Figure 4. Calulation of curvature basen on a circular mask.

In other words, if the curve divides the circle into two parts, curvature estimation is calculated by finding the ratio of the larger area to the smaller one. Note that if no curvature is found, the result of the equation will be one.

This equation is calculated for each point in the vascular skeleton provided from the previous step. Then, for the image which curvature is estimated for its m points, tortuosity is evaluated as follows:

$$\tau = \frac{1}{m}\sum_{i=1}^{m} \kappa_{2_i} \tag{4}$$

In the above equation, κ_{2_i} is the curvature in i^{th} point. Therefore, the calculated tortuosity is always more than one.

III. EVALUATING THE ALGORITHM

For evaluating this algorithm, two datasets are used. The first one is Grisan et al.'s image dataset [4]. This dataset includes 30 artery segment images and 30 vein segment images in which the main vessel is manually extracted and then the tortuosity is evaluated on this part. Furthermore, these two image categories have been rated by a specialist according to their tortuosity level.

The second image dataset includes 10 complete pictures from the retina which are prepared in Khatam-Al-Anbia hospital in Mashhad and also have been sorted by a specialist according to their tortuosity level.

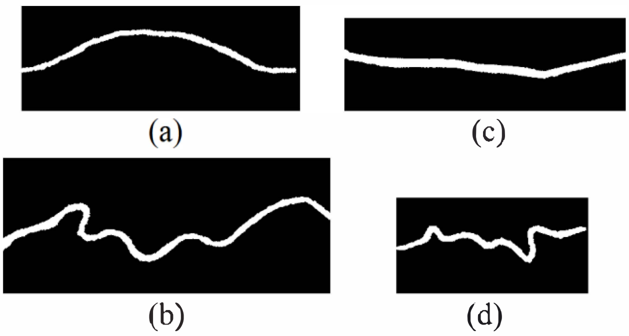

Figure 5. Four samples of images consit of the main vessel that extracted from Grisan's dataset. (a) and (b) are shown the least and most tortuosity in artery's images and (c) and (d) in vein's images.

In both of these two cases, tortuosity is evaluated by the proposed algorithm and the resulting level is compared with the results provided by the specialist by using Spearman Correlation Coefficient.

Table I compares the Spearman Correlation Coefficient in the proposed algorithm and Grisan's results. For evaluating tortuosity in a vessel, Grisan first divides it into some sectors. The boundary between these sectors is found according to the changes in the sign of curvature. In each sector, curvature is calculated based on the ratio of the length of the curve to the distance between the ends of the curve.

As can be seen, the proposed algorithm has a little bit poorer results than the Grisan's, but has the advantage that this algorithm is much simpler.

However, employing the proposed algorithm for the second image dataset leads to Spearman Correlation Coefficient of 0.952 which is an excellent result. If these images are numbered based on their tortuosity, Table II shows the tortuosity measure for them.

TABLE I. COMPARISION OF SPEARMAN CORRELATION COEFFICIENT FOR GRISAN NAD PROPSED ALGORITHM

Turtuosity Measure	Arteries	Veins
Grisan et al. [4]	0.949	0.853
Proposed algorithm	0.935	0.845

TABLE II. THE TORTUOSITY MEASURE FOR KHATAM-AL-ANBIA DATASET

Image #	Tortuosity
1	1.11932
2	1.12621
3	1.12618
4	1.14252
5	1.12698
6	1.13039
7	1.15194
8	1.1689
9	1.18302
10	1.17012

IV. CONCLUSION

In this paper a simple and efficient algorithm for measurement of vessel tortuosity in retinal images is presented. The main idea for this measurement is based on employing a circular mask. The center of this mask is put on every point over the skeleton of vessels. While the skeleton of vessel splits the circle in each position, the local tortuosity is considered to be the bigger to smaller area ratio. Experimental results show the capability of this method for measurement of tortuosity.

As future works and for better evaluation of our algorithm, we are preparing a large dataset of images with different grade of tortuosity in Khatam-Al-Anbia hospital.

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