A SIMPLE ANALYTIC APPROACH FOR TRACKING RETINAL VESSELS AND MEASURING THEIR DIAMETERS

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Abstract: Retinal image processing provides tools for automatic diagnosis and monitoring of retinal diseases such as diabetic retinopathy (DR), age related macular degeneration (ARMD), glucoma and such. The properties of vessel structures on the other hand are widely utilized in locating morphologic structures such as optic disc and macula and in automatic diagnosis of the retinal diseases. Due to the importance of retinal vessels, we propose a simple approach for vessel tracking and measuring vessel diameter in retinal fundus images. Images having manually segmented retinal vasculatures are obtained from STARE database and used in this study. Our method first finds the midlines of the vessel network on the segmented images by employing Zhang-Suen thinning algorithm and then tracks the vessel branches through those midlines. Lastly, the diameters of the vessel segments in different parts of the vasculature are calculated along with the tracking operation. The performed test results show that the proposed automatic method is quite successfully tracks the vessel network and measure the diameter.

1 INTRODUCTION

Along with the advancements in technology, the number and capability of techniques used in medical fields are increased. For example, automated image analysis and processing is one of the most promising areas of computer vision used in medical diagnosis and treatment. In this context, retinal fundus images offering very high resolutions that are sufficient for most of the clinical cases provide many indications that could be exploited in diagnosing and screening retinal degenerations or diseases (Köse, 2006), (Köse and İkibaş, 2008). As a matter of fact, using modern image processing techniques in ophthalmology gained significant interest especially in the last 15 years. The developments include automated diagnosing and monitoring systems for conditions such as degenerations, DR, ARMD etc, and detection of retinal landmarks such as optic disc, vascular network, macula and such (Köse et al., 2009), (Köse et al., 2008). The automated tools in ophthalmology have significant contributions in that they offer a great potential to be used in operations on large data set, which requires a substantial trained human effort when they are manually processed. Using these tools could indeed save a lot of resources, and they are free from environmental effects, graders' bias and fatigue, and image quality. Therefore, the increasing demand for these kinds of tools and techniques will sure continue in the future.

Since retinal vessels are usually affected by the existing diseases in retina (American Academy of Ophthalmology, 1991), the diseases can be analyzed and diagnosed by measuring parameters such as vessel diameters, branch angles and lengths (Stanton et al., 1995), (Hutchins et al., 1976). On the other hand measuring vessel diameter is not an easy task because of variation in vessel morphology and the quality of retinal images.

Even though quite number of methods proposed for measurement of vessel diameters, those methods mostly deal with not the direct measurement of the diameter but improving the accuracy of edge location. On the other hand, the measurement of parameters varies depending on the type of instruments used to record the vessel profile and the experience of the professional. The process is also very laborious and time consuming. Even though some improvement are done in estimating the vessel diameter by single Gaussian function modelling the vessel intensity profile (Newsom et al. 1992), the

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Gaussian model could fail in estimating diameter since high resolution fundus photographs often display a central light reflex (Gao et al., 2000).

Pappas et al. estimated the vessel diameter with an elliptical vessel profile and used a second order model for the background (Pappas and Lim, 1998). A method is presented by Gao et al. to model the intensity profiles over vessel cross-section using twin Gaussian functions to acquire adequate information for subsequent image characterization, leading to the development of automatic measurement system for retinal images. This method develops simple relationships between vessel width and the intensity distribution parameters, which provides robust estimators of vessel width even in the presence of image noise, and varying background intensities (Gao et al., 2001). A method of semi-automated image analysis for the measurement of retinal vessel diameters is described in (Newsom et al. 1992). The technique was compared with an observer-driven method for reproducibility and accuracy. A computerized system is presented for the automatic quantification of blood vessel topography. This system applies strategies and algorithms for measuring vascular trees and includes methods for locating the centre of a bifurcation, detecting vessel branches, estimating vessel diameter, and calculating angular geometry at a bifurcation. But the system had difficulty dealing with very noisy images and small or especially tortuous blood vessels (Gao et al., 2000). Another study presents an algorithm measuring the vessel diameter based on a two-dimensional difference of Gaussian model, which is optimized to fit a two-dimensional intensity vessel segment (Lowell et al., 2004). Although these methods work fine in healthy images, they fail in some cases such as pathological structure and low image quality. This study suggests a simple alternative method contributing to the automatic retinal image analysis. The developed method successfully tracks the vessel network and measure vessel diameters.

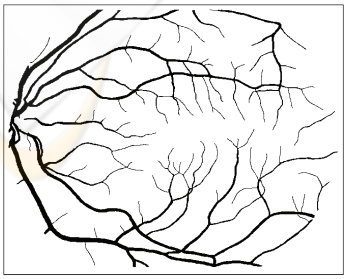

Figure 1: A sample manually segmented vessel network taken from STARE project.

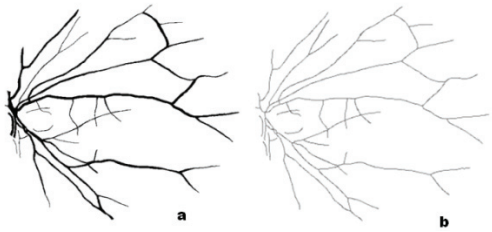

Figure 2: (a) Manually segmented retinal vessel network, (b) Skeleton of (a) generated using Zhang-Suen thinning algorithm

The rest of the paper is organized as the following. In Section 2, we will give the algorithm development for vessel tracking and measuring the vessel diameter. Section 3 explains the test results on manually segmented retinal images obtained from STARE project. Conclusions and future works are given in Section 4.

2 ALGORITHM DEVELOPMENT

This study introduces an algorithm for tracking vessels and measuring their diameters. The suggested method is applied on manually segmented images obtained from STARE project website. The STARE project includes detailed measurements of the anatomical structures and lesions visible in the retinal images. Here, our method first applies a thinning algorithm on those images to get midlines of the vessels, and then the vessels are tracked and their diameters are measured.

2.1 Vessel Segmentation

Vessel segmentation is the first phase to track the vessel network. Since our method does not have any tool for segmentation, we directly used the retinal images with manually segmented retinal vessels obtained from STARE project web site (http://www.parl.clemson.edu/stare/, 20.03.2009). An example of segmented binary vessel network image is given in Figure 1.

2.2 Skeletonization and Thinning

Skeletonization is a way of describing the global properties of objects and representing the original images more compactly. The skeleton, constructed with the width of one pixel, shows the structural connectivity of the main components of an object. Skeletonization techniques are applied in quite number of different areas such as character

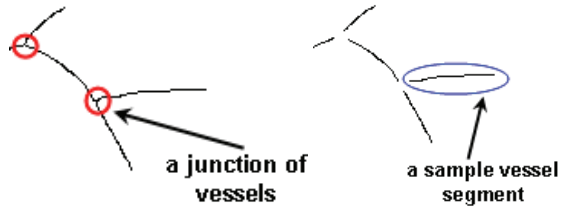

Figure 3: Removed junctions and generated sample vessel segments.

recognition problems and extracting vessel topology in retinal images.

Thinning is one of the basic methods for skeletonization. As a result of this iterative technique, the skeleton of vessel network is extracted. According to this technique, the edge pixels having at least one adjacent background point are removed from the vessel in every iteration. All of these kinds of pixels can be deleted, if their removal doesn't affect the topology of the vessel network. Here, the generated skeleton represents the shape of the vessel network with fewer pixels as in Figure 2.b (Ritter and Wilson, 1996).

The Zhang-Suen Thinning Algorithm is employed in this study (Ritter and Wilson, 1996), (Russ, 1992). In this skeletonization algorithm, the new value is obtained based on the previous iteration in a parallel manner.

The algorithm is finalized if no more change is needed at the end of either sub iteration. Figure 2 shows an example of the thinning process produced by using Zhang-Suen Algorithm.

2.3 Obtaining Vessel Segments

After the thinning operation, the crossing points of all vessel networks are obtained. According to crossing points, the vessel network is divided into segments and each segment is labelled with different numbers. A small part of sample retinal vessel network separated in to segments is shown in Figure 3.

Relatively small vessel segments are omitted if their length is less than 8 pixels. At the end of these operations, vessel segments are ready for tracking and measuring their diameters, which is explained in the following section in detail.

2.4 The Vessel Tracking Method

Vessel tracking method is an important phase of measurement of vessel diameter since our algorithm tracks the vessel midline points while measuring the thickness of the vessel segments in different parts of the network.

According to our algorithm, consecutive points on vessel midlines are considered in tracking. In each step of tracking, based on the location of current point, direction vector is determined to be the vector connecting P_{c-2} and P_{c+2}. Even though the direction vector could have been simply defined based on the difference of the first and last point of currently processed points, the average of the vectors in Figure 5.a and b better represent the direction of current point. Here, the direction vector is calculated considering five points, two of which are located before the current point and the other two are located after the current point. Totally five points are processed in determination of vessel direction for the current point, which is explained in Section 2.5 in details. The tracking method goes on until the end point is reached as shown in Figure 4.

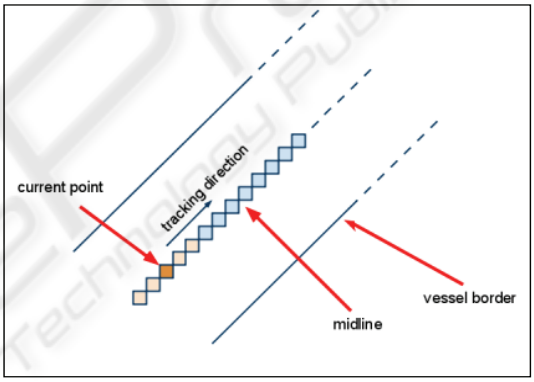

Figure 4: The midlines of vessel network utilized in tracking and measuring the vessel diameters.

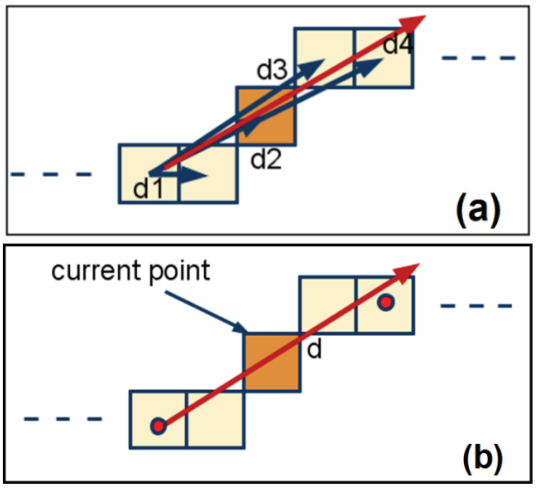

Figure 5: Graphical representation of (a) difference vectors and (b) the calculated direction vector based on difference vectors.

2.5 Measuring the Vessel Diameter

So far, the operations to obtain points on midlines of the whole vessel network are performed. The next steps include calculation of the direction vectors and measuring the vessel diameters.

In order to track the vessel branches, we first calculate the direction vector for each point on the midline produced using thinning algorithm. Here the direction vector is calculated as the average of five vectors. Relative to the current point P_c , the five points are P_{c-2}, P_{c-1}, P_c, P_{c+1}, P_{c+2}. Each point has axis and ordinate called x and y. The differences between the first point $P_{c-2}$and all other points represent different vectors as shown in Figure 6.a. The result vector representing the direction for the current point is shown in Equation 1.

$$\vec{d} = \overrightarrow{d_1} + \overrightarrow{d_2} + \overrightarrow{d_3} + \overrightarrow{d_4} \quad (1)$$

where $\overrightarrow{d_1}$, $\overrightarrow{d_2}$, $\overrightarrow{d_3}$, and $\overrightarrow{d_4}$ represent the vectors based on the difference between each point P_{c-1}, P_c, P_{c+1}, P_{c+2} and the first point P_{c-2}. The formula for calculation of these vectors is given in Equation 2.

$$\vec{d}_i = P_{c-2+i} - P_{c-2} \quad (2)$$

where i is 1, 2, 3 and 4. This operation is conducted for each point on the vessel midlines. The calculated vector is then normalized and orthogonal vectors used in measuring the vessel diameters are found for the current point.

Given the direction vector $\vec{d} = (d_x, d_y)$, the orthogonal vectors $d_{o1}$and d_{o2} are calculated to be $d_{o1} = (-d_y, d_x)$ and $d_{o2} = (d_y, -d_x)$. These orthogonal vectors are shown in Figure 7.

Measuring the diameter of vessels is done considering the direction vector. For each point through the midlines, two orthogonal vectors to the direction vector are calculated. The diameter for the current point is calculated to be the addition of distances starting from the current point and ending in vessel edges through these orthogonal vectors in both directions as depicted in Figure 6. Here, the diameter is the total length of d_{o1} and d_{o2}, which are orthogonal vectors to the direction of the current point. The vectors used in calculations are all normalized vectors.

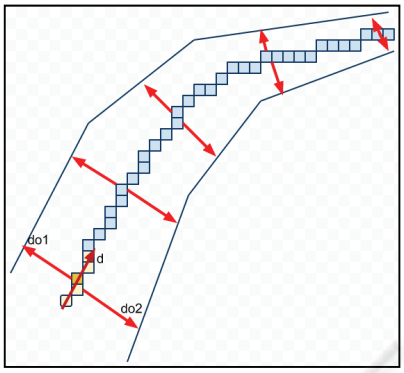

Figure 6: The orthogonal vectors calculated for each pixel through the midlines of vessel network, and measuring the vessel diameter.

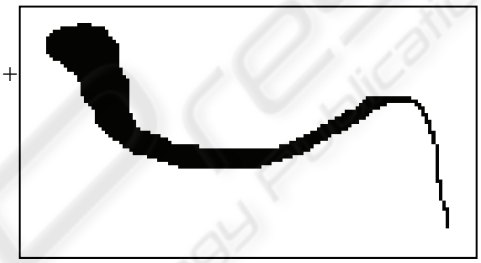

Figure 7: An example of manually generated test vessel segment.

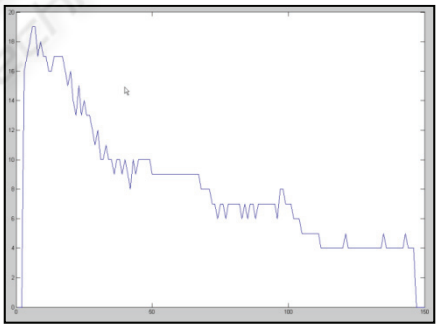

Figure 8: The calculated diameter of different parts of test vessel segment in Figure 7.

3 RESULTS

The proposed methods for tracking retinal vessels and measuring their diameter are tested on the images with manually segmented retinal vessels obtained from STARE project web site (http://www.parl.clemson.edu/stare/, 20.03.2009). It is illustrated in Figure 7 and 8 that the proposed methods successfully track the vessel network and measure the diameter of vessels in retinal images. The calculated diameters of a vessel segment are

also depicted in a graph in Figure 8. A real vessel network is also processed to show the vessel structure and calculate the diameters in different part of vessel network. One example of this covering a small part of the whole network is illustrated in Figure 9. The diameter of real vessel segment shown in Figure 9 is also graphically presented in Figure 10. These figures show that the graphical representation of the size of diameters is perfectly understandable and give ideas about the gradual change in diameters of vessels. The graphical representation can be a visual tool for ophthalmologists to see if there is any sudden change in vessel diameter, which could be a sign of different retinal diseases such as lesion and haemorrhages, bleeding etc.

In Figure 8, the x axis shows in which part of the vessel of Figure 7 the diameter is measured, and y axis shows the calculated diameter on that point. As seen in the figure, the diameter of vessel decreases through the vessel segment which is correct for the processed vessel. Figure 9 and 10 also shows an original retinal image, the extracted vessel segment from the image, and the diameter calculated on the extracted vessel segment. y and x axis show the calculated diameter and on which point of the vessel segment the diameter is calculated. Manual calculations of vessel diameters in some points also show that automatic and manual measurements throughout the processed vessel segment are very close to each other.

Overall, the suggested method successfully tracks the vessels and measures their diameters through the vessel segment. Here it can be stated that the method is successful in tracking and measurement in all kinds of retinal vessels.

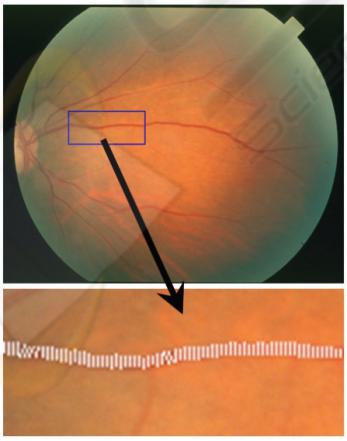

Figure 9: A retinal fundus image and a small part of the real retinal vessel network.

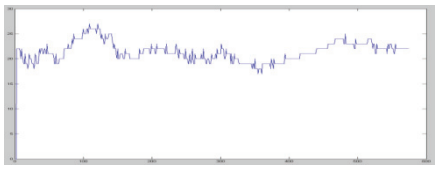

Figure 10: Diameters of vessel shown in Figure 9.

4 CONCLUSIONS

Tracking vessels network in retinal images and measuring the diameters are very important since the morphological changes in vessel structures can be a sign of different retinal diseases. For example sudden diameter changes can be a sign of haemorrhages or bleeding area. The vessel diameters can also be utilized in verification of vessel segmentation. Since the diameter of vessel structure gradually decreases while moving away from optic disc region, the sudden changes in diameters of segmented vessels would be a sign of inaccurate segmentation if the retinal image does not contain any disease. The direction vector would also be employed in the same way. The direction vectors of branches in vessel structure are supposed to be in similar direction with the main root vessel from which the branches originate. Especially in junctions of vessel networks, illogical direction vector of branches would be a sign of erroneous segmentation.

In addition to graphical representation, vessel colorization based on the diameter of vessels can be done as a feature work of this study for a better representation. This could also be a visual tool for ophthalmologist to visually detect the retinal diseases, the major sign of which is the changes in diameters.

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