

Retina vessel width estimation using bifurcation points to track vessels

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Abstract

Retina vessel segmentation is a challenging task that concerns scientists for many years. Vasculature gives us information for possible diseases like diabetic retinopathy, hypertension etc. Different algorithms have been developed using matched filters, pattern recognition techniques and scale-space techniques, which present reliable results. Currently the most challenging task is the estimation of vessels' width of the whole retina vasculature. At this article, a method for the calculation of vessels' minimum, maximum and mean width of every single vessel that we obtain from the already segmented binary image is proposed. Having this information we can evaluate the cardiovascular functionality, such as volumetric flow, flow velocity, and tension at the vessels' walls during blood circulation. The proposed algorithm tracks the bifurcation points of the whole vasculature using the skeleton of the initial image and uses a decision making technique to decide which vessel to cross each time. Finally the algorithm crosses the vessel pixel-by-pixel and calculates the width until the end of the vessel. The whole procedure is automatic and we can see the remaining skeleton in our screen, after estimating a single vessel's width, since this vessel disappears from the image. Each vessel's width is calculated with pixel accuracy.

Keywords: Centerlines, Vessel's width, Retina, Bifurcation points, Skeleton

1. Introduction

Developing an algorithm for the estimation of vessel's width, from already segmented retina images is a demanding task, not only during the designing process, but also during the algorithm's development. Extracting geometric information from vessels may help cardiologists evaluate the whole cardiovascular function of a patient [1], or even detect possible diseases.

Current methods in literature [2, 3] calculate width, by estimating the distance between two points, where the profile intensity of each vessel, changes at about 50%. Another method [4] uses a value of 1.96 for the standard deviation as half-width of the vessel, based on the fact that an implementation within ± 1.96 , accounts for the 95% of the whole vasculature implementation.

On the proposed algorithm, vessels' bifurcations are the points of interest and the fundamental part of the implementation. After extracting these points, we have two new vessels starting from that point, beside the main vessel that we already cross. Since we have three possible options (first new vessel, second new vessel and main vessel), a decision making part has to be developed in order each time to decide which vessel to cross first and estimate its width. For that purpose we need to calculate the gradient of the line at each bifurcation point and the angle of each vessel so as to decide which vessel to start crossing. Finally, we use the skeleton of the image to extract the corresponding vessel and calculate its width from the initial image.

The main steps of the algorithm can be seen on the flowchart in figure 1. All the images that have been used for the development of the algorithm were obtained from a diabetic retinopathy screening program in Netherlands, conducted by the Department of Radiology of the University Medical Center Utrecht, called DRIVE database.

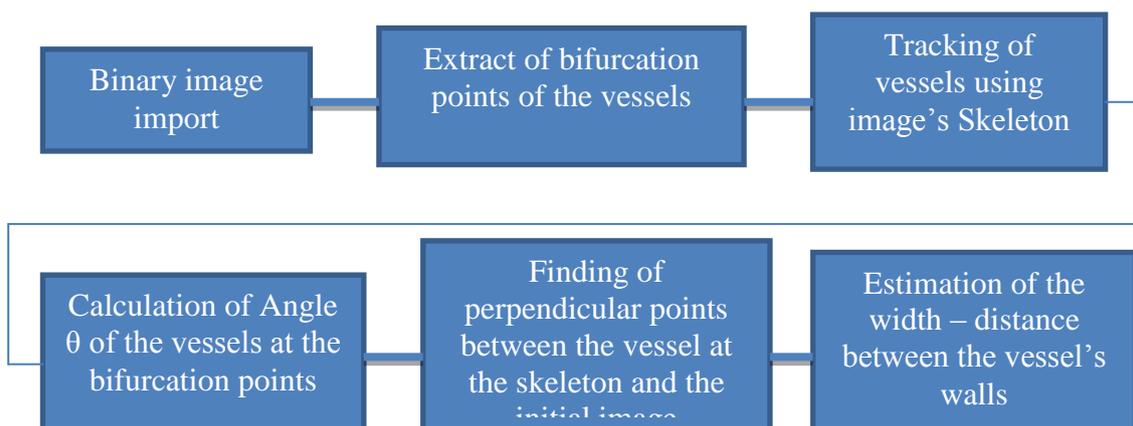


Figure 1. Flowchart showing the whole function of the algorithm

2. Finding bifurcation points

In order to find the Skeleton of the initial image, we are using a morphological operation which skeletonizes the binary image. This removes pixels on the boundaries of objects but does not allow objects to break apart. The pixels remaining make up the image skeleton.

After obtaining the image's skeleton, we use the Hit-or-Miss transform which finds certain patterns within the binary image, using a structural element. The result of this operation is different positions, where the first structural element fits with the image's foreground whereas the second structural element does not fit at all.

In binary morphology, we perceive an image as a subset at the Euclidean space R^d or as a set of integer Z^d for a given distance d . A structural element has a predefined shape, which can be represented from a binary image and is used as a standard for multiple morphological operations.

Assuming that we have two structural elements, C and D , which satisfy the equation $C \cap D = 0$. The pair (C,D) is called a complex structural element. So, in our case, the hit-or-miss operation of an image A given $B=(C,D)$, can be described from the following equation:

$$A \odot B = (A \ominus C) \cap (A^c \ominus D)$$

where A^c is the set complement of A . A point x of an image K belongs to the outcome of the hit-or-miss transform only if the structural element C , which corresponds with the point x , fits with image A . Respectively, the structural element D , which corresponds with the point x , does not fit with image A (fits with its background).

In our case, the steps that we follow are the followings:

- We calculate the skeleton of our binary image that can be seen in figure 2
- We create a matrix, which will be filled with all the bifurcation points that the algorithm will track
- A 3-by-3 window is used, in order to compare the eight neighbors of every point. Since a bifurcation point is defined only if three neighbor points can be found, three variables are used, so as to include all the possible combinations. For each of the three variables, we use nine values (0,1,2,3,4,5,6,7,8), in order each time to create a 3-by-3 window. The process initiates with a 3-by-3 matrix with a center point value of one:

$$\begin{matrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{matrix}$$

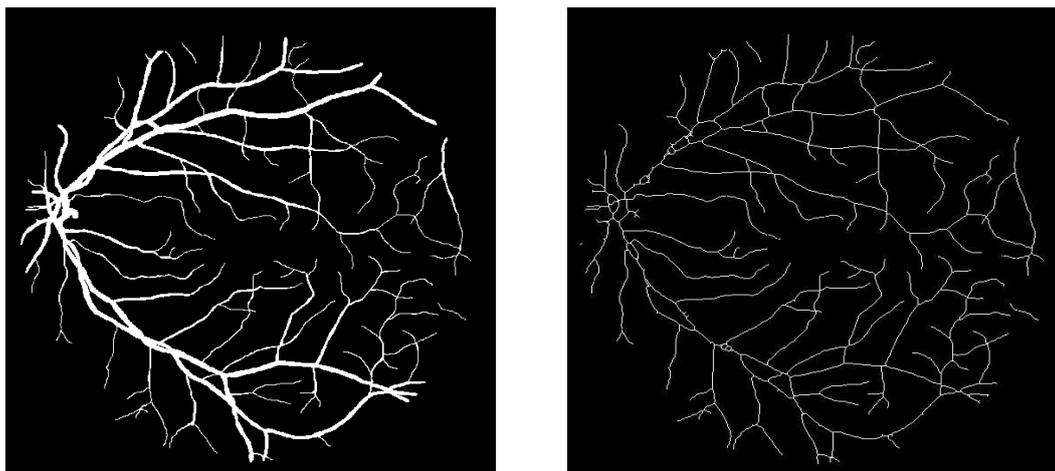


Figure 2. On the left side, the initial binary image can be seen. On the right side we see the relevant skeletonized image

Eventually, for every iteration, only the points that correlate with the above hit-or-miss transform between the skeleton and the structural element that was created above, are kept. In figure 3, we can see the initial binary image and the bifurcation points that have been extracted with the method that has been described above.

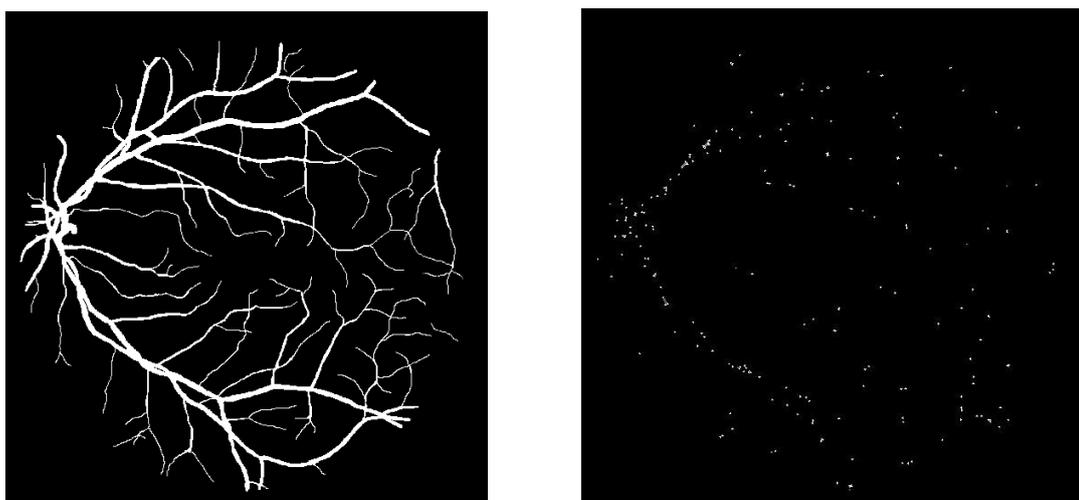


Figure 3. On the left side we have the initial binary image. On the right side we can see all the bifurcation points that have been extracted

3. Tracking of the vessels from the bifurcation points

The tracking process of the corresponding vessel, initiates from the relevant bifurcation point. The first step includes finding the gradient of line λ for the bifurcation point that has been chosen. Finding the gradient of line λ , gives us the direction of the vessel, making it easier to track the vessel. During vessel's crossing, we are finding the perpendicular points of the vessel's walls to the vessel's centerline. For that specific situation we have the following two cases:

- a) The first case refers to the vessel being parallel to X axis, which means that we move laterally in two angles: i) 90° and ii) -90° .
- b) The second case must include all the other possible situations where the vessel is not parallel to X axis. Therefore a window is used, in order to cross the vessel step-by-step in both directions of X and Y axes (0 1; 1 0; 1 1; -1 -1; -1 0; 0 -1). In this way we

can check all these points and see which one is closer to the parameter λ , that has been calculated for that specific bifurcation point. By the time that we want to know the angle θ every time, we are using the $\arctan(y)$, where $-\pi/2 < y < \pi/2$.

The algorithm, in order to calculate the width, needs three inputs:

- a) A bifurcation point
- b) The image skeleton
- c) The initial image

4. Estimating vessel's width

When a bifurcation point is chosen, the algorithm crosses the skeleton until another bifurcation point is found or not to have a neighbor. Just like it was mentioned above, after finding the relevant skeleton, then the algorithm is trying to detect the vessel's boundaries so as to extract the vessel and estimate its minimum, maximum and mean width.

From the bifurcation point, which is the initial point of a vessel, the algorithm finds the relevant point in the initial image in order to cross the vessel in both X and Y axes and finally find the width of that vessel. The process calculates the width as long as a white pixel is found on the axes. If the algorithm detects a black pixel laterally, terminates and calculates the width on both sides of the centerline. The estimation of the width terminates simultaneously with the vessel's end point. This point is found during the crossing process, where when we move forwards we always have a white pixel. If a black pixel is found, it indicates that the vessel has terminated and the algorithm proceeds to another vessel.

5. Results

In figure 4, we can see the extraction of two vessels using the proposed method, which includes three values:

- a) Minimum width, which refers to every single vessel and is defined as the minimum distance of the vessel's walls from the centerline.
- b) Maximum width, which is defined as the maximum distance of the vessel's walls from the centerline and,
- c) Mean width, which is the mean value of all the widths that have been calculated for a specific vessel.

Since it is unknown for the DRIVE database, the correlation between the pixels of the image and the metric values in μm , vessel's width is calculated by calculating the total number of pixels.

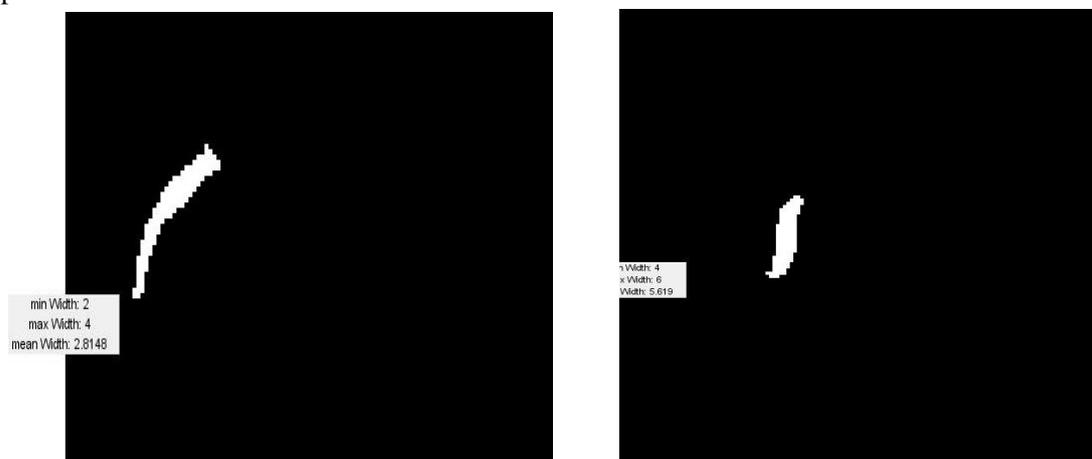


Figure 4. This figure shows us two isolated vessels and the estimation of the maximum, minimum and mean width.

In figure 5, it is worth seeing how the algorithm works. As mentioned above, after the calculation of a vessel's width, this vessel is excluded from the next skeleton. So after the estimation of all the vessels' width, then the final skeleton image will be a totally black image.

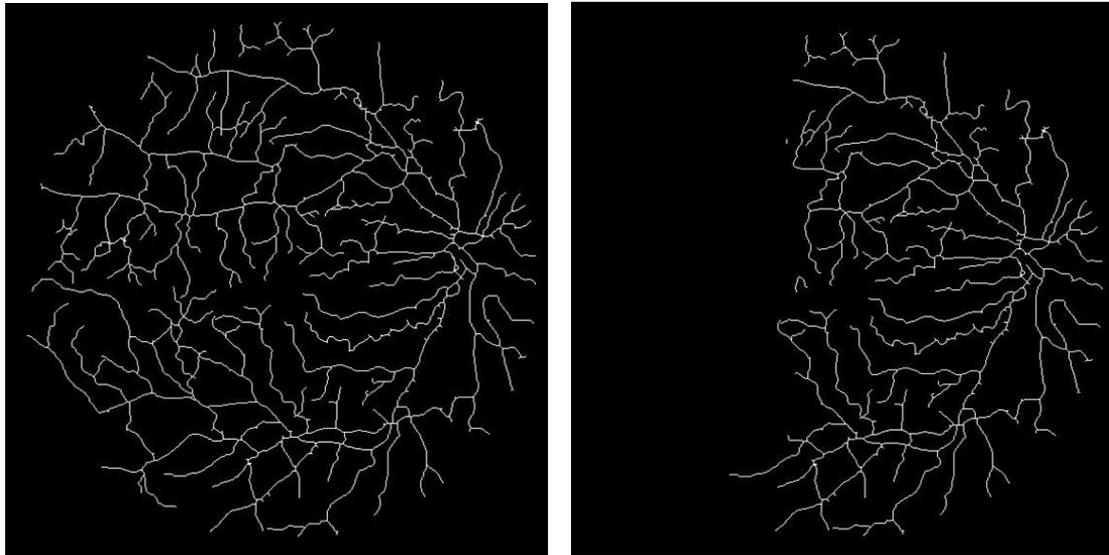


Figure 5. On the left side we can see the skeleton of a binary image. On the right side we can see the remaining skeleton after the calculation of several vessels' width.

6. Future work

In some cases, the vasculature appears very tortuous, which means that sometimes a vessel can be calculated twice from the algorithm, or in some cases a vessel may be partitioned in two smaller vessels and calculate their widths separately. That is not a major problem, since most of the time, the desired outcome is to figure out whether we have a vessel with stenosis within a vasculature or not. So even if a vessel is partitioned, the estimation of its width will proceed normally. Therefore, a logical next step would be to adjust the algorithm accordingly in order to detect vessels' tortuosity and minimize the errors that arise from the partition of a single vessel in two smaller vessels.

7. Conclusion

The proposed method was developed with a limited knowledge from literature. Extracting geometric information from vessels accurately is something that researchers are working towards and are also trying to achieve reliably. Given the limited prior knowledge, the results from the proposed method are quite interesting and the estimation of vessels' width is accomplished with pixel accuracy.

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