The Segmentation Method of Degree-based Fusion Algorithm for Coronary Angiograms

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***Abstract*—In allusion to the low contrast of the image between the backdrop and the small blood vessels, the blurred and fuzzy background of coronary artery image, a new blood vessel extraction method based on degree is proposed. First of all, two enhanced coronary angiograms are obtained from the original image by using two different image enhancement methods. Secondly, coronary arteries are extracted from two enhanced coronary angiograms through using the transition region extraction method based on degree, and then two extracted coronary artery images are acquired. At last, two extracted blood vessel images are fused, and the result of the fusion is the final segmentation image. The experimental results show that the backdrop can be eliminated and the small vessels can be remained effectively.**

***Keywords*—vessel segmentation; image enhancement; degree; morphological operator; Gaussian filter; coronary artery**

I. Introduction

Heart disease is a common disease in cardiology. The coronary angiography is an important diagnostic tool for doctors to diagnose the illness as heart disease. The essence of cardiovascular disease is blood vessel disease or abnormity. It is useful to make an accurate analysis of vascular structure and vessel morphology on the angiogram. It can offer valuable references for doctors to make precise diagnosis and treatment of heart patients. Therefore it is necessary to enhance the coronary angiograms and extract coronary arteries from the coronary angiograms.

At present, most of the vessel segmentation method is on the basis of grayscale characteristics. The images in [1] and [2] are enhanced by using Gaussian filter. Along directions perpendicular to the length of blood vessels, vascular grayscale profile can approximate Gauss curve [3]. But this method remains much more the image background. The image enhancement methods of [4], [5] and [6] are based on morphological operator. The pixel gray level of the vessel is lower than that of the background. The method of morphological Top-hat can not remove effectively the noise whose size is less than or close to the blood vessel. It only removes part of the noise.

This paper proposes a novel approach on the basis of degree-based fusion algorithm according to coronary vascular characteristics. Firstly, two enhanced vessel images are obtained by using two different image enhancement methods. Secondly, coronary arteries are extracted from two enhanced vessel images through using the transition region extraction method based on degree. Finally, two extracted vessels images are fused, and then the final segmentation image is acquired. The experimental results show that the backdrop can be removed and the small vessels can be preserved effectively. Moreover, the proposed approach is beneficial to 3d reconstruction of blood vessels.

II. Features of Coronary Blood Vessels

The properties of coronary blood vessels are as follows:

- The blood vessels can be regard approximately as piecewise linear segments, because the curvatures of the blood vessels are usually very small.
- The blood vessels appear darker relative to the backdrop because they have lower reflectance compared with the surfaces of other body tissues. Vascular grayscale profile can approximate gauss curve along direction perpendicular to the length of blood vessel, although different vessels have a bit different intensity profiles.
- The width of a blood vessel will decrease if it moves radially outward, but such a change in vessel caliber is considered a gradual one. So it can be assumed that the width of the blood vessels is nearly equal.

III. Image Enhancement Method

A. Morphological Top-hat

Top-hat is one of the image enhancement method[7]. Consider image $X = \{x_{ij}, i = 0,\cdots,u; j = 0,\cdots,v\}$, structuring element $A = \{a_{mn}, m = -M,\cdots,M; n = -N,\cdots,N\}$.

Morphological gray scale erosion $E(X, A)$ and dilation $D(X, A)$ are as follow:

$$E(X,A)=\{\min_{\substack{m=-M,\cdots,M\\n=-N,\cdots,N}}(x_{i-m,j-n}-a_{mn})\} \quad (1)$$

$$D(X,A)=\{\max_{\substack{m=-M,\cdots,M\\n=-N,\cdots,N}}(x_{i-m,j-n}+a_{mn})\} \quad (2)$$

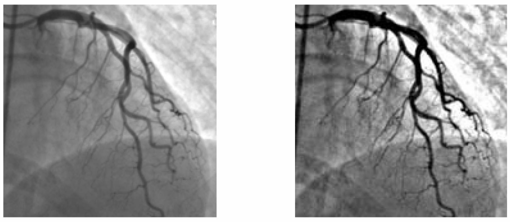
Morphological opening operation $O(X,A)$ and the Top-hat operator [8] are defined as

$$O(X,A)=D(E(X,A),A) \quad (3)$$

$$TH(X,A)=X-O(X,A) \quad (4)$$

It is important to select the shape and size of the structuring element. This paper chooses the round structuring element, because the shape of the vessel in cross section is approximated by a round. One hand, if the size is smaller than coronary arteries, the small vessels that are regarded as noises will be eliminated. On the other hand, if the size is too big, the amount of noises will increase, and useless objects will probably be extracted. So the size of the structuring element should be close to or slightly larger than the size of the vessel diameter, and the vessel can be enhanced clearly.

An original image and the enhanced image based on Top-hat are shown in Fig. 1(a) and Fig. 1(b).



(a) Original image (b) Enhanced image

Fig. 1. The image enhancement result used Top-Hat

B. Design of Gaussian Filter

The coronary arteries can be regard approximately as piecewise linear segments. Along direction perpendicular to the length of blood vessel, vascular grayscale profiles can approximate gauss curve [3]. Such a kernel can be expressed mathematically as

$$K(x,y)=-\exp\left(-\left(x^2+y^2\right)/\left(2\sigma^2\right)\right) \mid y \mid\leq L/2 \quad (5)$$

where L is the length of the segment, which the vessel is assumed to have a fixed orientation. In order to match with a vessel at an angle θ_i, let θ_i represent the orientation of the i^{th} kernel. Let $\overline{p}=[x,y]$ represent a discrete point of the kernel. The center of rotation is assumed to the origin [0, 0] in order to computer the weighting coefficients in the kernel. The rotation matrix is defined as

$$r_i=\begin{bmatrix}\cos\theta_i & -\sin\theta_i\\ \sin\theta_i & \cos\theta_i\end{bmatrix} \quad (6)$$

After rotating, the corresponding point in coordinate system is as follow

$$\overline{p_i}=[u,v]=\overline{pr_i} \quad (7)$$

A Gaussian curve extends infinitely along both sides of x axis, so it needs to be truncated at $u=\pm3\sigma$. After that, the corresponding coefficients for the i^{th} kernel are determined as

$$K_i(x,y)=-\exp\left(-\left(u^2+v^2\right)/\left(2\sigma^2\right)\right)\ \forall\overline{p_i}\in N \quad (8)$$

where $N=\{(u,v)\mid\mid u\mid\leq3\sigma,\mid v\mid\leq L/2\}$.

The mean value of the kernel is determined as

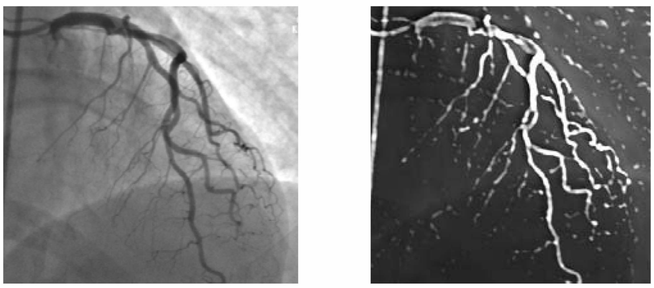
$$m_i=\sum_{\overline{p_i}\in N}K_i(x,y)/A \quad (9)$$

where A represents the number of points in N.

Then the Gaussian convolution kernel is expressed as

$$K_i'(x,y)=K_i(x,y)-m_i \quad \forall\overline{p_i}\in N \quad (10)$$

It is important that the direction of the blood vessel $\theta(0\leq\theta\leq\pi)$ is probably arbitrary. If the matched filter is aligned at an angle $\theta\pm\pi/2$, it will have its maximum value. If an angular resolution is presumed as angle of 30°, 6 different kernels are needed in order to match all possible directions. The experiments show that it will match well with a coronary artery when $\sigma=1.5$ and $L=9$. An original image and the enhanced image based on Gaussian filter are shown in Fig. 2(a) and Fig. 2(b).



(a) Original image (b) Enhanced image

Fig. 2. The image enhancement result Gaussian filter

IV. PROPOSED SEGMENTATION METHOD

A. Degree and Similarity

An image may be considered a graph $G = (V, E)$ that is weighted and undirected [9]. V is the node set of the graph whose total sum is N, and E is the set of edge. The pixels can be regarded as the nodes of the graph. $e_{i,j}$ is an edge which connects node v_i and node v_j, $e_{i,j} \in E$. $w(i, j)$ represents the similarity between pixel i and pixel j. The similarity function is expressed mathematically as

$$w_{i,j} = \exp[-\frac{D(x_i - x_j)}{2\sigma^2}] \tag{11}$$

where $D(x_i - x_j)$ represents Euclidean distance between pixel i and pixel j. The function of similarity is simplified as

$$w_{i,j} = \exp[-\beta c(i, j)] \tag{12}$$

where β express the scale parameter, $c(i, j)$ express the gray level difference between pixel i and pixel j.

The function of degree is defined as the sum of the edge weights, which connects with the same node. The degree d_i of the node v_i is determined as

$$d_i = \sum_{j=1}^{k} w(i, j) \tag{13}$$

where $i, j \in \{1, 2, \cdots, N\}$, k is the amount of edges that connects with the same node i.

B. Degree Segmentation Method

If a coronary angiogram is considered a graph, which is weighted and undirected, the image transition region can be extracted through the degree. Compute the degree value of each node in the graph. If the pixels are in the vessels or the background, they will have larger degree value, and their gray values are the same or similar. If the pixels are in the image transition region, they will have smaller degree value, and the differences of their gray values are obvious. From these values, it is easy found that some degree values are lesser than certain threshold. If these pixels are extracted, they will compose the image transition region. The final segmentation threshold can be acquired from the histogram of the transition region.

The image transition region is also be obtained by another method. All of pixels will be arranged according to their degree values from small to large. Set a percentage p, p is usually between $5\% \sim 15\%$, the transition region is made up of the top $p \times N$ pixels. N is the sum of the pixels in the image.

From above, the steps of the algorithm can be summarized as

- Regard the pixels as the nodes, regard the image as the graph. According to (12), compute similarity value of each pixel.
- According to (13), calculate the degree value.
- All of pixels will be ranged according to their degree values from small to large. Select a percentage p, transition region is composed of the pixels which are the top p.
- The final segmentation threshold is determined by histogram of transition region.
- The blood vessels are extracted through the threshold.

C. Fusion Method

In order to retain the tiny blood vessels and remove the backdrop, this paper proposes a new fusion algorithm. The fusion method is summarized as [10]:

- The coronary angiogram is enhanced by the method of morphological Top-hat. From the enhanced image, the blood vessels are extracted by degree method. Let F_1 represent the segmentation result.
- Using Gaussian filter enhances the same original image. From the enhanced image, the blood vessels are extracted by degree method. Let F_2 represent the segmentation result.
- Both in image F_1 and F_2, background is labeled value 0 and vessels is labeled value 1. From top to bottom and from left to right, make 3×3 neighborhood window move pixel by pixel all over the image F_1. If the value of the center pixel in image F_1 is 1, the value of the pixels connect with the center pixel are 1.
- Let F_3 represent the last segmentation result. If the value of pixel in image F_1 is 1, and the corresponding value in image F_2 is also 1, let the value of the pixel be 1 in F_3, or the value is labeled 0.

V. EXPERIMENTAL RESULT AND DISCUSSION

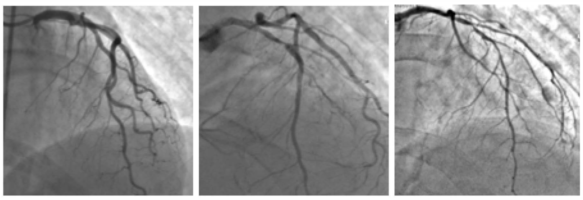
The experiment results of three different segmentation methods are given in Fig.3. Fig.3(a) is the original image, Fig.3(b) is the result of the degree method based on Top-hat, Fig.3(c) is the result of the degree method based on Gaussian filer, and Fig.3(d) is the result of the proposed method.

From Fig.3(b), (c) and (d), it is obvious that the method of Fig.3(b) not only removes the background but also eliminates the tiny branches of the blood vessels, while the method of Fig.3(c) not only retains the small branches of the blood vessels but also preserves the background. It is easily seen that the method of Fig.3(d) not only can retain effectively the tiny vessels, but also can get rid of the background effectively. In addition, when the local contrast of the image is quite low, the proposed method can extract the blood vessels effectively.

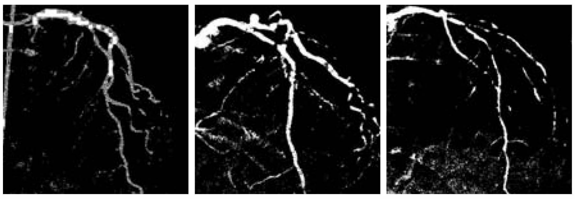
As parameter, the artery average diameter in the different methods is shown in Tab. 1. Tab.1 is the further proof that the proposed method can extract coronary arteries effectively. Let d represent the average diameter of the left anterior descending artery. Comparing these data, it is obvious that the data of the proposed method are the closest to the true values in the different methods. It further proved that the proposed method can extract vessels more effectively than the other methods mentioned in the paper.

VI. CONCLUSION

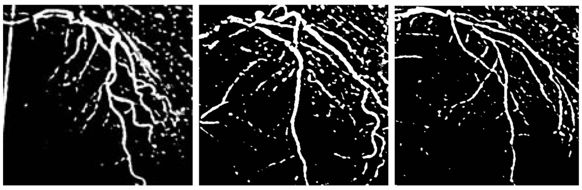
This paper proposes a novel approach on the basis of degree-based fusion algorithm for coronary angiograms. At first, the same original image is enhanced by using two different segmentation methods. Secondly, coronary arteries are extracted from two enhanced images through the degree method. Finally, two extracted vessel images are fused. The experiment results show that the proposed method can extract vessels more effectively than the other methods mentioned in the paper. Moreover, the proposed method is beneficial to diagnosis and 3d reconstruction of blood vessels.



(a) Original image



(b) Degree method based on top-hat



(c) Degree method based on Gaussian filter

(d) Result used the proposed method

Fig. 3. Segmentation result

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TABLE I. COMPARISON OF THE AVERAGE DIAMETER

	Image No.1	Image No.2	Image No.3
	d	d	d
True value	2.75	2.73	2.68
Method No. 1	2.69	2.78	2.64
Method No. 2	2.71	2.68	2.70
Method in the paper	2.72	2.75	2.70

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