Segmentation Method Based on Fusion Algorithm for Coronary Angiograms

Wenwei Kang , Ke Wang, Wanzhong Chen
College of Communication Engineering
Jilin University
Changchun, Jilin Province, China

Wenying Kang
Cardiovascular Department
the Second Hospital of Jilin University
Changchun, Jilin Province, China

***Abstract*—Aiming at weak contrast between the coronary arteries and the background, a new segmentation method based on fusion algorithm is proposed. Firstly, the coronary arteries are extracted by using the maximizing entropy segmentation method based on Top-hat. Then the coronary arteries are extracted again by using the maximizing entropy segmentation method based on Gaussian filter. Finally, the last segmentation result is the image obtained by fusing two extracted coronary arteries images. A lot of experiments indicate that the proposed method outperforms the maximizing entropy method based on not only Top-hat but also Gaussian filter about the small vessels extraction and background elimination. In addition, the method is indeed valuable for diagnosis and the quantitative analysis of vessels**.

Keywords-coronary angiogram; Top-hat; Gaussian filter; maximizing entrop; image fusion

I. INTRODUCTION

The coronary angiography is an important examination for a diagnostic tool in cardiology. It is useful to precise diagnosis and treatment of patients to make an accurate analysis of vessel morphology on the angiogram. So it is necessary to extract vessels from the coronary angiogram. But usually there are several problems for extract vessels: weak contrast between the coronary artery and the background, an apriority unknown and easily deformable shape of the vessel tree, sometimes overlapping strong shadows of bones and so on. Hence, it is important to enhance the image and then extract the vessels.

There are many previous works on extracting blood vessels from coronary angiograms. At present, the most of methods of vessel segmentation is based on gray-level feature. Utilizing the feature that the gray-level of the background is higher than that of the vessel, [1], [2] and [3] enhance the vessels used morphological operator, then extract the vessels used mean filter template. The segmentation method of Top-hat can eliminate the part of noise, but it can not eliminate the noise whose size is nearer or lower the size of vessel. In two-dimensional matched filter approach [4] and [5], the Gaussian filter is used to enhance the image, because the blood vessel gray-level profiles along directions perpendicular to their length can be approximated by a Gaussian curve [6]. But this method preserves not only the small vessels but also the background.

This paper analyzes the characteristics of coronary angiograms, and then a new segmentation method based on fusion algorithm is proposed. Firstly, the original coronary angiogram is enhanced respectively by using the Top-hat method and the Gaussian filter method, so obtain two enhanced images. Secondly, two extracted coronary arteries images are obtained used the maximizing entropy threshold method from two enhanced images. The segmentation method based on Top-hat can eliminate the background, at the same time the small vessels are eliminated. While the segmentation method based on Gaussian filter can preserve the small vessels, simultaneously the background is preserved. Hence, two images of the extracted coronary arteries are fused at last. The experiments indicate that the proposed method outperforms the maximizing entropy method based on Top-hat and Gaussian filter about the small vessels extraction, connectivity and effectiveness. In addition, the method is indeed valuable for diagnosis and the quantitative analysis of coronary arteries.

II. PROPERTIES OF THE CORONARY ARTERIES

Coronary arteries usually have the following properties:

- Since the blood vessels usually have small curvatures, the coronary arteries may be approximated by piecewise linear segments.
- Since the vessels have lower reflectance compared to other body tissues surfaces, they appear darker relative to the background. Gray-level profiles of the cross section of coronary arteries have an intensity profile, which can be approximated by a Gaussian curve, although the intensity profile varies by a small amount from vessel to vessel.
- Although the width of a vessel decreases as it travels radially outward, such a change in vessel caliber is a gradual one. It will be assumed that all the blood vessels in the image are almost equal width.

III. IMAGE ENHANCEMENT METHOD

A. Morphological Operators

In this section, some operators used in the paper will be shown. Most of them are morphological operators used on gray scale image. Consider image $X = \{x_{ij}, i = 0, \cdots, u; j = 0, \cdots, v\}$, structuring element $A = \{a_{mn}, m = -M, \cdots, M; n = -N, \cdots, N\}$.

1) Morphological gray scale dilation and erosion [7]: The morphological gray scale dilation of X by A is denoted by $D(X, A)$ and defined as

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

The morphological gray scale erosion of X by A is denoted by $E(X, A)$ and defined as

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

2) Morphological opening operation: To use structuring element performs an opening operation $O(X, A)$ to the original images X, namely, firstly to erode the original image, and then to dilate the image, the mathematical formula is as follow

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

3) Morphological Top-hat: The Morphological Top-hat operator [8] is frequently defined as

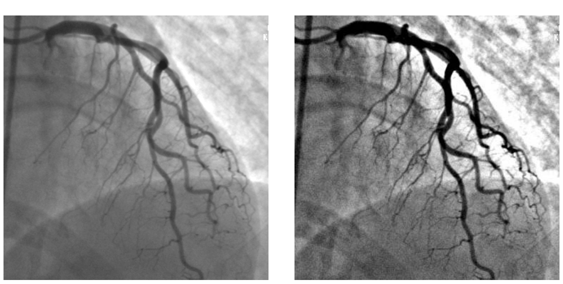
$$TH(X,A)=X-O(X,A) \quad (4)$$

As the Top-Hat operator is able to detect the local elevations on arbitrary background, it can be used to enhance the vessel part. The significant components of the operation are the size and the shape of the structure elements. From define of Top-hat operator, if the size of structure element is bigger enough than the vessels that will be interested in, unexpected objects will possibly be detected. On the other hand, if the size of structure element is smaller than the vessels, the contrast between the vessels and background cannot be detected surely. So, in order to enhance vessel parts clearly, it is necessary to choose the structure element nearly the same or slightly large in size than diameter of the vessel. In the paper, the shape of the cross section of the vessel can be approximated by a round, the round structure element is chosen.

An original coronary angiogram is given in Fig. 1(a), the enhancement result of Top-hat method is given in Fig. 1(b).

B. Design of Gaussian Filter

The blood vessels may be considered as piecewise linear segments. The vessel gray-level profiles along directions perpendicular to their length can be approximated by a Gaussian curve. Such a kernel may be mathematically expressed as



(a) The original image (b) The enhanced image

Figure 1. The enhanced image used Top-Hat

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

where L is the length of the segment, which the vessel is assumed to have a fixed orientation. Here the direction of the vessel is assumed to be aligned along the $y-$ axis. For the vessels at different orientations, the kernel has to be rotated accordingly. The two-dimensional matched filter kernel in a discrete grid is designed as follows. Let $\overline{p}=[x,y]$ be a discrete point in the kernel and θ_i be the orientation of the i^{th} kernel matched to a vessel at an angle θ_i. In order to computer the weighting coefficients for the kernel, it is assumed to be centered about the origin [0, 0]. The rotation matrix is given by

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

and the corresponding point in the rotated coordinate system is given by

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

A Gaussian curve has infinitely long double sided trails. The trail is truncated at $u=\pm3\sigma$. A neighborhood N is defined such that $N=\{(u,v) \,\|\, u\,|\le 3\sigma, |\,v\,|\le L/2\}$. The corresponding weights in the i^{th} kernel are given by

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

If A denotes the number of points in N, the mean value of the kernel is determined as

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

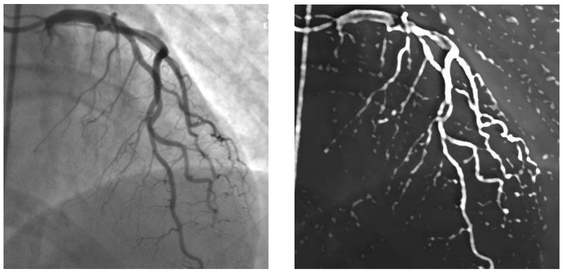
Thus the convolution mask used in this algorithm is give by

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

It must be noticed that a vessel may be oriented at any angle $\theta(0\le\theta\le\pi)$. The matched filter will have its peak response only when it is aligned at an angle $\theta\pm\pi/2$. In the paper, assuming an angular resolution of 30°, 6 different kernels are needed to span all possible orientations. Thus, the corresponding responses are to be compared, and for each pixel only the maximum response is to be obtained. A lot of experiments prove that $\sigma=1.5$, $L=9$ can be matched well with a blood vessel for coronary angiogram. An original coronary angiogram is given in Fig. 2(a), the enhancement result of Gaussian filter method is given in Fig. 2(b).

IV. MAXIMIZING ENTROPY THRESHOLD METHOD

Maximizing entropy segmentation method [9] is to select a suited threshold to segment an image into object and the background. If the size of an image is $M\times N$, gray value probability of the image can be described as



(a) The original image (b) The enhanced image

Figure 2. The enhanced image used Gaussian filter

$$p_i = \frac{n_i}{M \times N} \tag{11}$$

where n_i is the pixel numbers with gray value i .

The prior entropy of the image is defined as

$$H_T = -\sum_{0}^{255} p_i \ln p_i \tag{12}$$

If the object and the background are respectively denoted by Λ_1 and Λ_2 , and segmentation threshold is t , the prior probability of the object and the background may be described as

$$\left.\begin{aligned} H_{\Lambda_1} &= -\sum_{i=0}^{t} \frac{p_i}{p(\Lambda_1)} \ln \frac{p_i}{p(\Lambda_1)} \\ H_{\Lambda_2} &= -\sum_{i=t+1}^{255} \frac{p_i}{p(\Lambda_2)} \ln \frac{p_i}{p(\Lambda_2)} \end{aligned}\right\} \tag{13}$$

where

$$p(\Lambda_1) = \sum_{i=0}^{t} p_i$$

$$p(\Lambda_2) = \sum_{i=t+1}^{255} p_i$$

$$p(\Lambda_1) + p(\Lambda_2) = 1$$

The information sum $I(\Lambda_1, \Lambda_2)$ of the object and the background is

$$I(\Lambda_1, \Lambda_2) = H_{\Lambda_1} + H_{\Lambda_2} \tag{14}$$

When $I(\Lambda_1, \Lambda_2)$ reaches the max value, t is the most suited threshold.

In the paper, two extracted coronary arteries images are obtained used the maximizing entropy method from two enhanced images, that are used respectively by the Top-hat method and the Gaussian filter method.

V. FUSION ALGORITHM

The maximizing entropy method based on Top-hat can eliminate the background, but at the same time the small vessels are eliminated. The maximizing entropy method based on Gaussian filter can preserve the small vessels, simultaneously the background is preserved. Hence, a new segmentation method based on fusion algorithm is proposed. This method not only eliminates the background but also preserves the small vessels. The fusion algorithm is as follow

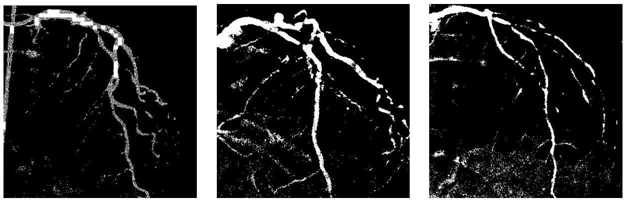
- The original image is enhanced by using Top-hat method, and then the coronary arteries are extracted by using maximizing entropy segmentation method. The extracted vessels image is denoted by F_1 .
- The same original image is also enhanced by using Gaussian filter method, and then the coronary arteries are extracted again by using maximizing entropy segmentation method. The extracted vessels image is denoted by F_2 .
- The value 1 describes vessels, and the value 0 describes background in both F_1 and F_2 . Let 3×3 neighborhood window move pixel by pixel within the image F_1 from left to right and top to bottom. If the value of the pixel is 1 in F_1 , the value of the pixels in its 8-adjacnt connection area is labeled 1.
- If the pixel is labeled 1 in F_1 and the value of the corresponding pixel in F_2 is also 1, then the pixel is labeled 1 in F_3 , the other pixels are labeled 0 in F_3 . F_3 is the last segmentation image contains the coronary arteries.

VI. EXPERIMENTAL RESULT AND DISCUSSION

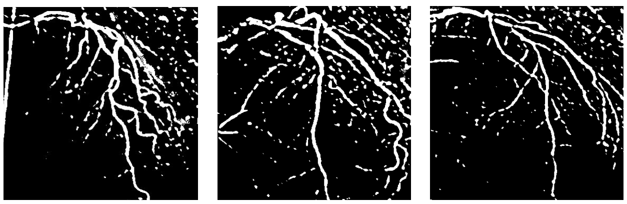
50 coronary angiograms come from China-Japan Union Hospital Jilin University are segmented. Three results of them are showed in Fig. 3. The original image is given in Fig. 3(a), The result used the maximizing entropy method based on morphological Top-hat is given in Fig. 3(b), the result used the maximizing entropy method based on Gaussian filer is given in Fig. 3(c), and the result of the application of the proposed method is given in Fig. 3(d).

When the result in Fig. 3(b), (c) and (d) are compared, it is readily seen that the maximizing entropy method based on Top-hat eliminates not only the background but also the small vessels, while the maximizing entropy method based on Gaussian filter preserves not only the small vessels but also the background. It is obvious that the proposed method not only can eliminate the background but also can preserve the continuity of the small vessels in the image, and perform effectively in detecting blood vessels even when the local contrast is quite low.

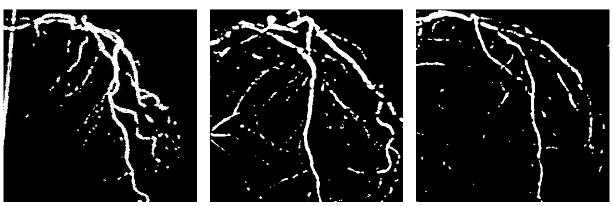
(a) The original image



(b) Maximizing entropy method based on Top-Hat



(c) Maximizing entropy method based on Gaussian filer



(d) The result used the proposed method

Figure 3. The image segmentation process

VII. CONCLUSION

The paper presents a novel segmentation method based on fusion algorithm for coronary angiograms. At first, the original coronary angiogram is enhanced respectively by using the Top-hat method and the Gaussian filter method. Secondly, two extracted coronary arteries images are obtained by using the maximizing entropy threshold method from two enhanced images. Finally, two extracted coronary arteries images are fused. The experiments indicate that the proposed method outperforms the maximizing entropy method based Top-hat and Gaussian filter about the small vessels extraction, connectivity and effectiveness. In addition, the method is indeed valuable for diagnosis and the quantitative analysis of coronary arteries.

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