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A Segmentation method of Coronary Angiograms based on Multi-scale Filtering and Region-Growing

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Abstract— **In this paper, we propose a simple and powerful method for segmentation of the coronary artery in angiograms, which combines Hessian matrix multi-scale filtering and region-growing. In this method, Hessian matrix multi-scale filtering is used to enhance vessel in angiographic images. The multi-seed region-growing algorithm is used to extract the coronary artery tree from the enhanced images. As considering the characteristics of the X-ray angiographic images and the advantages from both, the proposed method is sensitive to the vessel-like structures and robust to noise in the angiograms. Using this method, both the coronary artery trees and most of smaller distal vessels could be extracted clearly. The results show that the proposed method is suitable for the segmentation of coronary angiograms, and is available for further accurate quantitative analysis to coronary angiograms.**

Keywords-coronary angiography, Hessian matrix, region-growing, vessel segmentation

I. INTRODUCTION

Cardiovascular disease serious harm to human health, it will take away more than 12 million lives each year, nearly a quarter of the total number of deaths in the world [1]. It is often caused by coronary artery stenosis and blockage. Coronary artery play an extremely important role in the supply of blood to the heart, and coronary atherosclerosis is the main reason of heart damage and myocardial infarction. Hence accurate analyses of vascular patterns have become essential for diagnosis and treatment.

Coronary angiography is an important method of diagnosis of heart disease, which is recognized as the gold standard for diagnosis of the cardiovascular disease. Especially in China, X-ray coronary angiography is widely used. The vascular contrast agent makes the vessel become lighter than other organizations. However, the interpretation to the angiographic images is impaired by the effect of vessel foreshortening, overlap and noise because of the uneven distribution of the contrast agent and the environmental noise influence of image processing. In order to improve the level of clinical diagnosis, the extraction and segmentation of coronary artery from X-ray angiographic images is very necessary, at the same time extracting distinct vascular patterns is a crucial premise to vascular quantitative analysis and 3D visualization.

With the numerous vascular branches and complex patterns of the coronary artery, the segmentation algorithm is facing great challenges. Vessels appear on the whole tree structure, and the vascular wall presents tubular structure. The current methods of vessels detection are to grasp the characteristics of tubular structure of vessels. Frangi et al. presented a vascular enhancement method that was based Hessian matrix multi-scale filtering[2], the relationship among the eigenvalues of the Hessian matrix was used to detect and extract the tubular structure from images. This method has be confirmed that is an effective vascular enhancement approach. In this study, the method is adopted. However, this enhancement algorithm is only based on the geometry structure of the vessels, the extracted vessels are not continuous, and hardly distinguish between true and fake vessels. Thus, in this paper, we propose a segmentation method of the coronary artery which combined Hessian matrix multi-scale filtering and region-growing. Region growing algorithm is a simple and effective method to extract vessels using the spatial continuity of the vascular tree. In this method, we make an improvement on the growing process by adopting the criterion that multi-seed grow at the same time. The multi-seed region-growing method can reduce computation time evidently, also make much contribution to connect the discontinuous vessels and detect the small and distal vessels. In this paper, Hessian matrix multi-scale filtering is used to enhance vessel in angiographic images, and the region-growing step is performed on the enhanced images to extract vessels. Experiment results have shown that the proposed approach can obtain satisfying segmentation results.

II. METHOD

A. *Vessel enhancement algorithm based Hessian matrix*

Due to the uneven distribution of the contrast agent and the environmental noise impact of imaging process, the angiographic images are impaired by the effect of vessel foreshortening, overlap and noise. A vessel enhancement procedure as a preparing step will improve small vessel delineation and reduce organ over-projection. In this study, we use a method based on Hessian matrix to enhance the vessels in original angiographic images.

A three-dimensional curved surface can be defined by two-dimensional coordinates of pixels and their corresponding gray-values, which can be expressed in the following form:

$$C = \{(u,v,I); I = (u,v)\} \quad (1)$$

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Where (u, v) is two-dimensional coordinates of pixels and $I = (u, v)$ is the corresponding gray-value.

The curvature of this curved surface can be defined with Hessian matrix [3], which follows that

$$H = \begin{bmatrix} I_{uu}(u,v) & I_{uv}(u,v) \\ I_{vu}(u,v) & I_{vv}(u,v) \end{bmatrix} \quad (2)$$

Where $I_{uu}(u,v)$, $I_{uv}(u,v)$, $I_{vu}(u,v)$, $I_{vv}(u,v)$ are the second derivative of images, $I_{x,y} = \frac{\partial I^2}{\partial x \partial y}$

In order to reduce noise, the second derivative of images in a point x_0 is defined as a convolution with derivatives of Gaussians at scale σ :

$$I_{x,y}(x_0, \sigma) = \sigma^2 G_{x,y}(x_0, \sigma) * I(x_0) \quad (3)$$

$$G(u, v, \sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp(-\frac{u^2 + v^2}{2\sigma^2}) \quad (4)$$

Where $G(u, v, \sigma)$ denotes a Gaussian filer at scale σ .

Frangi et al. proposed the following norm based the eigenvector of Hessian matrix [2]. It is shown as Table I. Eigenvalues and eigenvectors of the Hessian matrix can indicate the important features of three-dimensional curved surface. To each point in 2D images at such a scale, we can obtain two eigenvalues of Hessian matrix, a large negative λ_1 and a small eigenvalue λ_2 of positive or negative, that is $\lambda_1 < 0$ and $|\lambda_2| \ll |\lambda_1|$.

In the certain scale case, the eigenvector that correspond with the larger absolute eigenvalue indicates direction at this point that is corresponded by maximal curvature; by contrast, the eigenvector that correspond with the smaller absolute eigenvalue indicates direction of minimal curvature[2].

We use a simplified response function to extract the vessel structure [5] [6], it follows that

$$Z(x, y, \lambda_1) = \begin{cases} \log(|\lambda_1| + 1), & \lambda_1 < -1 \\ 0, & others \end{cases} \quad (5)$$

The function value $Z(x, y, \lambda_1)$ determine the probability whether this point belongs to vascular points. We will obtain the enhanced image via applying this function to each pixel in image.

TABLE I. THE JUDGEMENT NORM OF VESSELS

orientation pattern	**2D image**	
	λ_1	λ_2
noise	N	N
tubular structure(bright)	H-	L
tubular structure(dark)	H+	L
blob-like structure(bright)	H-	H-
blob-like structure(dark)	H+	H+

If adopting the single-scale case analysis, part of pixels belonging to vessel cannot meet the norm that the equation (5) adopts, leading to the dissatisfy enhancement results. In order to solve the problem, using multi-scale analysis is necessary. The respond function at different scales is defined as follows:

$$Z(x, y, \lambda_1(\sigma)) = \begin{cases} \log(|\lambda_1(\sigma)| + 1), & \lambda_1(\sigma) < -8\log(\sigma) \\ 0, & others \end{cases} \quad (6)$$

This response equation provides a vessel discriminant function at scale σ . Where $\sigma = \sigma_{1,}\sigma_{2,}...,\sigma_n$, σ_1 and σ_n are the minimum and maximum scales, determined by the range of vessel diameters in the angiographic images.

The maximum response across multiple scales is considered as the optimal solution, and is given by the following equation:

$$E(x, y) = \max_{\sigma=\sigma_1,\sigma_2,...,\sigma_n} Z(x, y, \lambda_1(\sigma)) \quad (7)$$

In this paper, the range of scale value is from 1 to 9 and the interval is 2 in terms of the features of images.

B. Region-growing

Region-growing algorithm is a simple and effective method to extract vessels which makes use of the spatial continuity of the vascular tree, but the traditional region-growing algorithm is unsatisfying for the segmentation of coronary artery, which may lose distal vascular branches. In this paper, we make an improvement on growing process, we adopt the criterion that multi-seed grow at the same time, produce several dispersal regions, and merge the homogeneous regions. Hence, the region merge criterion need to be proposed, which determine whether two regions should be merged. The regions merge criterion is a homogeneity test. Two adjacent regions can be merged if passing the homogeneity test. The homogeneity test is established according to the analysis of image features by gray-scale histogram and K-means clustering [7]. The improvement of region-growing method can reduce computation time evidently.

The region-growing algorithm consists of the seed selecting, growing rules and convergence principle. A neighborhood is defined about each pixel in the image. The extent of neighborhood depends on the characteristics of the image [8]. Guided by regional feature analysis, the region-growing process puts the points which locate around the seed and have similar features to the seed into same region. Four or eight neighborhoods of the pixels are generally used in the 2D images.

The seeds selecting depends on the nature of the images. We adopt an interactive way to select seeds. This method is simple and conventional. In order to obtain more accurate segmentation results, taking the center of the region as a seed will be effective.

Gray-scale histogram and K-means clustering method analysis is performed on the selection of thresholds; we assess region homogeneity from feature distributions, and select a suitable threshold to establish the growing norm.

According to the feature analysis of the angiograms, the threshold range is from 7 to 19. In the experiment, the smaller threshold in this range corresponds with the less noise and more completed segment results. The growing rule based on this threshold is established, it is given as follows:

$$\left| I(x,y) - mean(x,y) \right| < \delta \tag{8}$$

Where $I(x,y)$ is gray-scale value of each pixel in the image, $mean(x,y)$ is the mean of nine points including eight neighborhoods and the selected seed. δ is the threshold.

The segmentation processes terminate if no points are found to match the equation (8).

C. *The framework of methods*

In order to express the implementation process of the proposed method clearly, the overview of the proposed framework for the segmentation of X-ray angiograms is shown as follows, including 5 major steps.

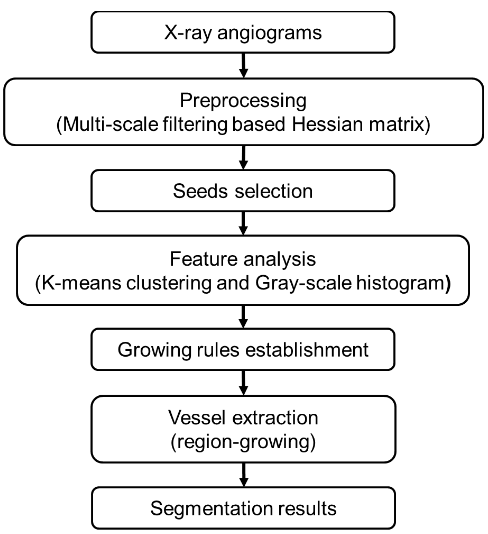

Figure 1. Overview of the proposed framework for the segmentation of X-ray angiograms

III. RESULTS

Extensive experiments are performed on the angiograms. And the segmentation results are shown in Figure 1.

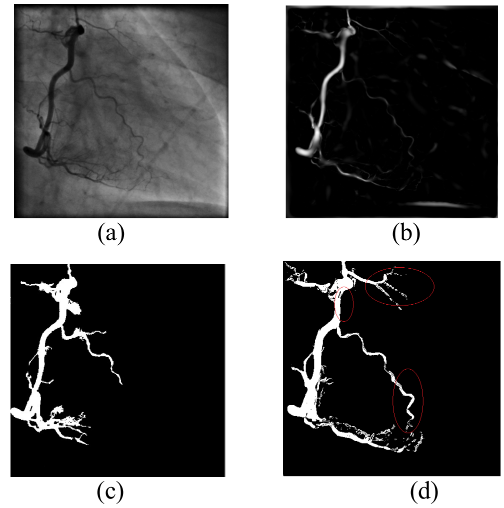

Figure 2. (a) original angiogram. (b) enhanced image using multi-scale filtering based on Hessian matrix. (c) result without enhancing filtering. (d) result of the proposed method.

In the pre-process, we used single-scale filtering to enhance the images, but found that it had lots of miss-judgment. Hence, multi-scale filtering is adopted eventually. Fig2. (b) is the result of multi-scale filtering based on Hessian matrix, which can detect most vessels, and suppress background and noise. However, the contrast is low in the enhanced images. Parts of the extracted vessels are not continuous, hardly distinguished between true and fake vessels in some positions. Fig. 2(c) shows the result without enhancing filtering. Most of distal and small vessels lost are detected. Fig. 2(d) shows the result of the proposed method. And the parts labeled by red circles can reflect the significant advantages of our method, Compared with Fig. 2(b), the small and distal vessels are particularly enhanced, and most of discontinuous vessels are connected. Other results are shown as Figure 3.

Figure 3. Left: original angiograms. Middle: enhanced images using multi-scale filtering based Hessian matrix. Right : results of the proposed method.

IV. CONCLUSION

We proposed an efficient method for segmentation of angiograms which combines multi-filtering based on Hessian matrix and region-growing. The idea of this method is pellucid, which implemented region-growing on the enhanced results. This method is particularly effective for noise suppression and the extraction of small and distal vessels. The multi-seed region-growing algorithm can reduce computation time observably, and also make much contribution to connect the discontinuous vessels and detect the small and distal vessels. Experiment results have shown that the proposed approach effectively can carry out satisfying segmentation results.

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