Extraction of Vascular Tree on Angiogram with Fuzzy Morphological Method

Kaiqiong Sun[1], Nong Sang[2], and Erdun Zhao[3]

[1] Institute for Pattern Recognition and Artificial Intelligence, Huazhong University of Science and Technology, 430074 Wuhan, P.R. China
[2] Key Laboratory of Ministry of Education for Image Processing and Intelligent Control, Huazhong University of Science and Technology, 430074 Wuhan, P.R. China
[3] Depart. of Computer Science, Central China Normal University, 430079 Wuhan, P.R. China

kqsunn@yahoo.com.cn,nsang@hust.edu.cn,erdunz@263.net

Abstract

Vessel segmentation algorithms are critical components of circulatory blood vessel analysis systems. A novel morphological method for extraction of coronary artery tree on angiogram is presented in this paper. Morphological Top-Hat operator is applied to enhance the contrast between the vessel and background. A combination of the fuzzy morphological opening with a set of linear structuring element is introduced to lessen the noise along the direction of vessel as well as decrease the noise in the background. Threshold of the image after fuzzy morphological filter produces the vascular tree. Experimentation studies show that the method presented can hardly obtain the entire consecutive vascular tree structure whereas deals with vessel with different diameter by the identical operator. It is also fast and automatic.
Keyword: Segmentation, vascular tree, angiogram, fuzzy mathematical morphology.

I. Introduction

The X-ray angiogram is an important examination tool in clinical medicine. A quantitative analysis of the coronary artery tree on angiogram with the aid of computer is useful for precise diagnosis of cardiac and cerebral disease. It could be used for finding vessel malformation [1] as well as 3D reconstruction of coronary artery from 2D projective image to 3D representation [2] for surgery navigation or choosing the optimal view point. For the quantitative analysis of vessel the foundational process is the detection of coronary artery tree on angiogram.

Because of that the X-ray angiogram is the projection of the 3D reality into a 2D representation after injection of the patient with a radio-opaque dye before imaging, the consistency of the dye within the vessel, the depth of the vessel, and the noise during the imaging process result in image that is a challenge. Which poses a problem of segmentation with weak contrast between the vascular tree and the background, an apriority unknown and easily deformable shape of the vessel tree, sometimes overlapping strong shadows of bones and so on.

A Related Work

Over the past years, various computer algorithms have been proposed to segment coronary artery tree from angiograms. We refer the reader to [7] for a general review of the techniques and algorithms about segmentation of vessel. Among them mathematical morphological methods are one widely used pattern recognition methods. Mathematical morphology [3] is a nonlinear theory on image or signal processing. It originates from the set theory and processes image based on the viewpoint of set theory. The character of morphological image analysis is to construct some kinds of structuring element (SE) as well as the application to the image with the structuring element, which relates to the image to analyze. Useful information can be obtained through the operation. The morphological gray scale dilation and erosion compose two main morphological operators. The morphological gray opening, erosion followed by dilation, is an important nonlinear filter related with the shape and dimension of the structuring element used.

Most morphological operator for vascular tree segmentation takes advantages of the property of opening that it can remove the bright object which can not contain the used structuring element and reserve those being capable of accommodating the structuring element. Two groups of structuring element are usually applied to extract vascular tree on angiogram, which are devised to delineate different property of the image respectively. One of them is the structuring element designed bigger than the dimension of vessel and used to get the information of background of vessel. Through subtracting the result image by opening operator, on which the vessel is removed, from the original image, the vascular tree could be enhanced. This is the usually called Top-Hat operator, in which the disk-shaped or square structuring elements are usually chosen. Then other techniques follow it to acquire the last vascular tree, such as dynamic programming [4] and region growing in terms of the intensity difference of neighboring pixels [5]. Simply threshold of the enhanced image after Top-Hat operator usually can only get part of the vessel, which is also disconnected, in [10] different characters of the segmented part are used to refine the result to connected vessel tree.

Another group of the structuring element is those designed to be contained by the vascular structure, which is used catch the information of vessel directly. The vessel is a kind of piecewise linear pattern. Thus the linear structuring is natural introduced to extract the vascular tree on angiogram. Thackray and Nelson [6] use a set of 8 morphological operators to extract vascular segments, each of which represents an oriented vessel segment. The system also applies an adaptive thresholding scheme to extract the vascular segments from the intensity image. The method does not extract the vascular interconnection structure. As [7] states that the range of vessel widths the system handles appears limited by the setting of the 8 morphological operators. Zana and Klein [8] use 12 linear structuring elements for extraction of vessels on retinal angiography. However, they take different strategy for big vessels and small vessels.

It should be pointed out the two qualities about the gray opening. To extract vessel on angiogram, the second group structuring elements used, as mentioned above, must be small enough to be contained by the vessel. On the other hand, the intensity of any point on the result image by opening operator will be lower than that on original image. However, the entire medical image is ill-posed. The discontinuity of intensity along the direction of vascular tree makes the result of opening suffers from it. Moreover, the dimension of vascular tree varies in different place of the angiogram. Thus no appropriate structuring element can be contained by any vessel structure while having the ability removing the noise of background at the same time. For our view too much additional processing after morphological filter or different processing for different vessel part contrary shows the weakness of the filter method or the structuring elements adopted for segmentation of vessel on angiograms. It also means that the capabilities of morphological filter do not take effect on segmentation of vessel on angiogram evidently.

B. Our Work

In view of the fuzziness of angiogram, we present a new morphological method for extraction vascular tree on it. The key idea is to use fuzzy operator to extract the vascular structure. Two groups structuring elements mentioned above are integrated for segmentation. Morphological Top-Hat operator is applied to enhance the contrast between the vessel and background. A combination of the fuzzy morphological opening with a set of linear structuring element is introduced to lessen the noise along the direction of vessel as well as decrease the noise in the background. Threshold of the image after fuzzy morphological filter produces the vascular tree. In the next section, some operators used in this paper will be shown. In section 3 we explain the method presented. Section 4 presents the experimental result. A conclusion is given in the last section.

II. Morpholoical Operator

A. Gray Morphological Operators

Consider a digital image $X = \{x_{ij}, i = 1,...u; j = 1,...,v\}$ and a structuring element $A = \{a_{mn}, m = -M,...M; n = -N,..., N\}$. Morphological gray scale erosion, dilation, open, close and Top-Hat of *X* by *A* are defined as [3]:

$$X \Theta A = \{\min(X_{i-m,j-n} - a_{mn}) \mid m = -M,...,M; n = -N,...,N\} \ . \tag{1}$$

$$X \oplus A = \{\max(X_{i-m,j-n} - a_{mn}) \mid m = -M,...,M; n = -N,...,N\} \ . \tag{2}$$

$$X \circ A = (X \Theta A) \oplus A \ . \tag{3}$$

$$X \bullet A = (X \oplus A) \Theta A \ . \tag{4}$$

$$TH(X, A) = X - X \circ A \ . \tag{5}$$

B. Fuzzy Morphological Operators

Given an universe *U*, a map $\mu_X : U \to [0,1], x \mapsto \mu_X(x) \in [0,1]$ defines a fuzzy sets *X* on *U*. Many transfer function can be used to map an image *X* into a fuzzy set X'. On the normalized image fuzzy morphological erosion, dilation, opening, closing and Top-Hat of X' by *A* are respectively defined as [9]:

$$X' \tilde{\Theta} A = E(X', A) \ . \tag{6}$$

$$X' \tilde{\oplus} A = E^c(X'^c, A) = 1 - E(1 - X', A) \ . \tag{7}$$

$$X' \tilde{\circ} A = 1 - E(1 - E(X', A), A) \ . \tag{8}$$

$$X' \tilde{\bullet} A = E(1 - E(X', A), A) \ . \tag{9}$$

X' is normalized image of *X*. A is the structuring element. Fuzzy erosion can be computed by using different metricses. One of them is the average function:

$$E_{ave} = (X' \tilde{\Theta} A)_{ave} = 1 - \sum | X' - A | / sizese \ . \tag{10}$$

$sizese$ is the number of active pixels in the structuring element. More detailed explanation about the fuzzy morphological operators can be seen is in [9].

III. Material and Methods

The X-ray angiogram is the projection of the 3D reality into a 2D representation. Due to the variety of dye concentration following time and imaging noise, the clinical obtained angiogram is a fuzzy image with low contrast containing unclear vascular tree. On vision the vascular tree takes on consecutive tubular structures. Fig. 1 is a clinical digital subtraction angiogram (DSA) of head. Vascular tree area has comparatively small intensity to the local background area. We apply a series of morphological operator to extract the vascular tree based on the properties of angiogram and morphological operator. The full process is illuminated as follow.

A. Contrast Enhancement

Observation on the histogram shows that the intensity of angiogram concentrates on a small intensity scope. The concentration of intensity makes the image appear low contrast, which causes the difficulty of segmentation. Morphological opening operator can wipe off the light object with smaller dimension than the used structuring element. Thus opening with a structuring element having a little bigger dimension than the maximal diameter of vessel will remove the entire vascular tree on the angiogram. The local slowly varying background of vascular tree is acquired with this operator. Subtracting the obtained background image from the original image achieves the enhanced vascular tree image. This process is called Top-Hat operator:

$$IE = IO - IO \circ SE \ . \qquad (11)$$

IO is the original angiogram. IE is the enhanced vascular tree image. $\circ$ denotes the gray morphological opening operator defined by formula (3). SE is the used structuring element.
The significant component of Top-Hat operator is the size and the shape of the structuring element. In order to enhance vascular tree clearly, the structuring element is chosen slightly larger in size than the maximum diameter of the vessel. The flat disk structuring element with radius 15 pixels (the maximal diameter of vessel is about 24 pixels) is chosen to enhance the image. Fig. 2 shows the result image where the contrast between the vascular tree and background is clearly enhanced.

Most methods for segmentation of vessel on angiogram apply low-pass filter or edge-preserving median filter to the original image to remove random noise. Whereas experiment shows that any of two filters runs the risk of destroying or missing the vessel structure in the place of small vessel. Such filter is not suggested in this paper due to that the following fuzzy filter presented has the natural character to remove random noise while keeping the structure of vessel.

B. Fuzzy Morphological Filter

The enhanced image has clearer vascular tree shape than before. However, there is still much noise within vessel and background area. They pose the microcosmic discontinuousness of intensity along vascular tree direction and unevenness of background. As the morphological opening operator could reserve the light object on an image which can accommodate the structuring element, we can use fuzzy structuring element relating the vascular tree shape to reduce the noise, however, at the same time keep the vascular tree shape mostly.

The enhanced image is usually relatively dark. Linear intensity normalization is used to stretch the intensity scope to interval [0, 1]. Then the image can be treat as a fuzzy sets with intensity of each pixel representing the grade of membership belonging to vascular tree or not. Twelve linear structuring elements (every 15 degree between zero and 180 degree) with seven pixels length is chosen to fuzzy open the normalized image respectively. The pixel-wise maximum of the twelve result of fuzzy opening acts as the last result of the fuzzy filter:

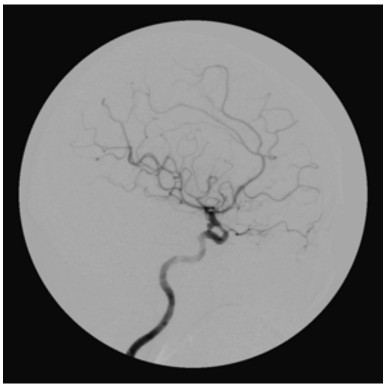


Fig. 1. Original image

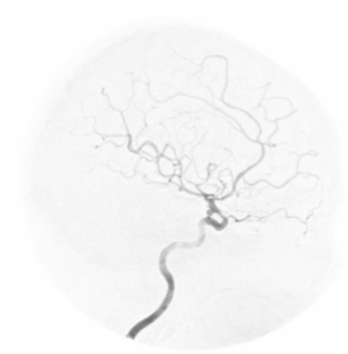


Fig. 2. Enhanced image

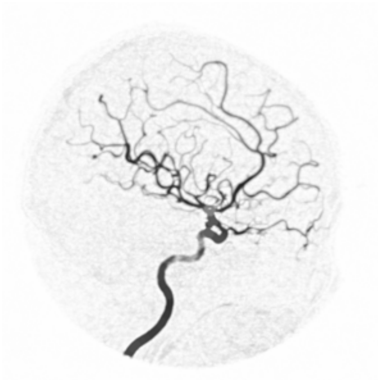


Fig. 3. Image after fuzzy filter

Fig. 4. Binarization of filtered image

Fig. 5. Vascular tree extracted

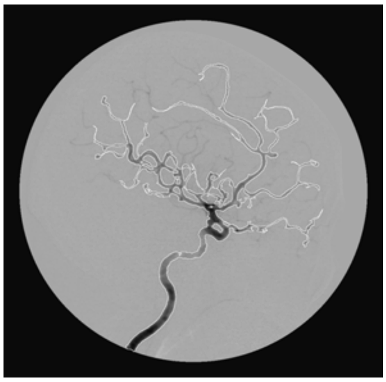


Fig. 6. Result imposed on original image

$$IR = \max_{i=1}^{N}(IE^{'} \tilde{\circ} SE^{i}) . \qquad (12)$$

IR is the fuzzy filtered result image. $IE^{'}$ denotes the normalized image from *IE*. SE^{i} i=1… *N* is the *N* direction linear structuring element used. *N* is 12 in this paper. $\tilde{\circ}$ denotes the fuzzy opening operator defined in formula (8), which differs from that used in formula (11). The average metrics in formula (10) is chosen here for the fuzzy opening of vascular tree extraction. Average metrics provides smoother erosion and it is very similar to the application of a median filter [9]. The formula (12) means that each point in the result image gets the intensity from the same location in the normalized image and equals to the mean intensity in the point along a certain direction with a certain length. The mean intensity along this direction has the maximal value of those in all directions. This direction is called most possible vessel direction. It smoothes both the intensity of vessel point and that of point on background while keeping the difference of intensity between vessel and the background. For the smoothed background will bring new local slowly varying background, the result image is enhanced again with the same structuring element as in and by formula (11). Fig. 3 shows the enhanced image after being filtered by formula (12). The intensity within the vessel region is much smoothed and the vascular takes good shape in the image. The noise in background is diminished much and it makes the vascular tree be likely to separate from the background by one threshold of intensity.

C. Threshold of Filtered Image

A fixed thresh of 49 is applied to the filtered image to generate a binary image. Fig. 4 shows the binary image. After binarization, few noises outside the region of the vessel still reside in the thresholded image. They are disconnected with the vessel part and can be removed through the binary morphological operators. Open the result image (reverse the image firstly) by a big structuring element and get a single connected region, which is a sub-region of the vessel. Reconstruct the single connected region to the (reversed) result image. Thus all the object part in the result image connected to the region is retrieved and is the last vessel part. Fig. 5 is the result of this processing and is the extracted vascular tree. Fig. 6 shows the result imposing the extracted coronary artery on the original angiogram. It shows that most vessel structure is retrieved though the filter used.

Ⅳ. Experimental Results

A. Comparison with Some Classic Edge Methods

Fig. 7 is another original angiogram. We apply some edge detection algorithms and that we propose to this image. Fig. 8 shows the extraction result of our proposed algorithm. Fig. 9 is produced by morphological gradient and Fig. 10 is the result of LOG detector. As the figures shows, the proposed method can easily detect nearly the whole structure of vascular tree structure. The fuzziness of angiogram makes the traditional edge detector algorithms fail to catch to whole structure information though having some satisfied result in some small pieces of vessel part.

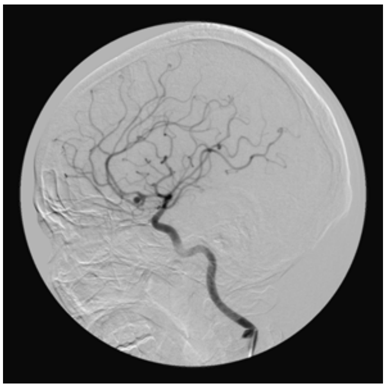


Fig. 7. Original angiogram

Fig. 8. Result of proposed method

Fig. 9. Morphological gradient

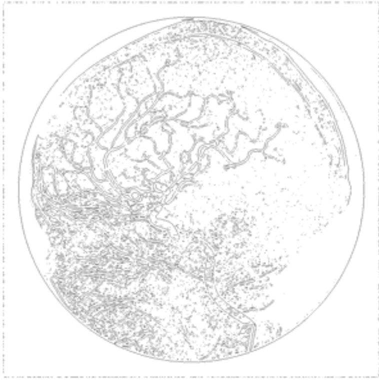
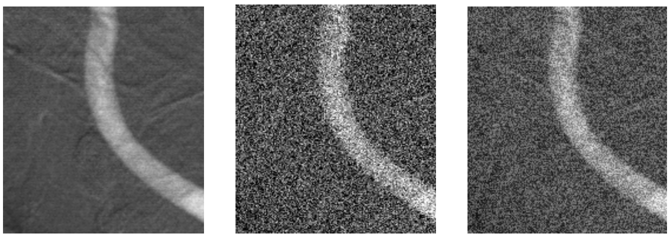


Fig. 10. LOG edge detector

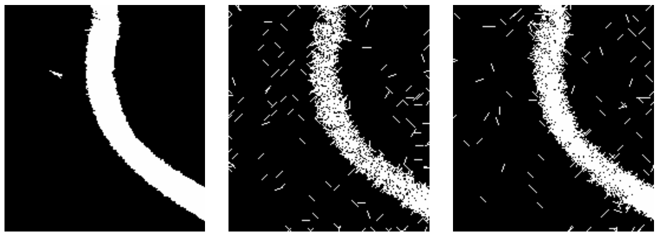
B. Robustness of the Method

We test for the proposed algorithm on image after adding different noise into the original angiogram. We also give the filter result by traditional morphological filter. Fig. 11 (a) is a part angiogram. Fig. 11 (b) and (c) are the image with 20 percents Gaussian noise and uniform noise respectively in Fig. 11 (a). Fig. 11 (d) (e) (f) are the extracted vascular tree structure by our proposed method on Fig. 11 (a) (b) (c) respectively. Replacing the operator $\tilde{\circ}$ in formula (12) with traditional gray opening $\circ$ defined in formula (3) results in Fig. 11 (g) (h) (i) from (a) (b) (c) respectively.



(a) (b) (c)

(d) (e) (f)



(g) (h) (i)

Fig. 11. (a) Original image. **(b)** With added Gaussian noise on (a). **(c)** With added uniform noise on (a). **(d)** Result from (a) by fuzzy filter. **(e)** Result from (b) by fuzzy filter. **(f)** Result from (c) by fuzzy filter. **(g)** Result from (a) by traditional filter. **(h)** Result from (b) by traditional filter. **(i)** Result from (c) by traditional filter.

Ⅴ. Conclusions

In this paper, we showed a method to obtain the important information of the shape and the location of the coronary artery tree by the morphological filter. There are two prominent peculiarities of our method what differs from the previous method for vascular tree extraction. Firstly, the same operator is applied to extract the vessel with different dimension. Secondly, the structuring element used is not strictly restricted about the dimension. The fuzzy filter introduced takes great effects on segmentation of vascular tree on angiogram. By the method in this paper, we can extract the almost entire coronary artery tree, which is also quickly. It makes the quantitative analysis of vessel easy.

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Kaiqiong Sun received his B.S. degree in Applied Mathematics from Huazhong University of Science and Technology, Wuhan, P.R. China, in 1994. He received the M.S. degree in Yangtze University. He is currently a Ph.D student in Institute for Pattern Recognition and Artificial Intelligence at Huazhong University of Science and Technology. His current research interests include Medical Image Processing and Bayesian Image Analysis.

Nong Sang graduated from Huazhong University of Science and Technology and received his B.E. degree in computer science and engineering in 1990, M.S. degree and Ph. D degree in pattern recognition and intelligent control in 1993 and 2001 respectively. He presently is a professor with the Institute for Pattern Recognition and Artificial Intelligence at Huazhong University of Science and Technology. His research interests are in the areas of pattern recognition, computer vision, and neural network, etc.

Erdun Zhao received his B.S. degree and M.S. degree in Applied Mathematics in 1994 and 1997 respectively, Ph. D degree in Electronics and Information Engineering in 2000, all in Huazhong University of Science and Technology. He is currently an associate professor with Department of Computer Science in Central China Normal University, Wuhan, P.R. China. His research interest includes data communication, computer network, neural network, etc.