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Research on Cerebral Aneurysm Detection Based on OPTA Algorithm

Jian Wu[1,2], Guangming Zhang[2], Jie Xia[2], and Zhiming Cui[1,2]
[1] JiangSu Province Support Software Engineering R&D Center for Modern Information Technology Application in Enterprise, Suzhou 215104, China;
[2] The Institute of Intelligent Information Processing and Application, Soochow University, Suzhou 215006, China
Email: szjianwu@163.com, szzmcui@suda.edu.cn

***Abstract*—It is the key step of the cerebral aneurysm recognition system to locate the cerebral aneurysm accurately and fast onto the image. A new detection method of cerebral aneurysm, which is based on the improved thinning algorithm, is proposed after analyzing the morphological characteristics of cerebral aneurysm fully in the paper. In this new detection method, the improved OPTA algorithm is used to get the skeleton tree of blood vessel firstly, and then cerebral aneurysms are detected by searching the skeleton tree. After doing lots of experiments, the cerebral aneurysm can be detected well by using this new method, which provides a premise for cerebral aneurysm recognition.**

***Index Terms*—OPTA, thinning algorithm, cerebral aneurysm detection, template matching**

I. INTRODUCTION

Cerebral vascular disease, especially cerebral aneurysm is one of the key factors leading to disease and death in adults, which threaten the health and life of human badly. With the development and the unceasing maturation of computer technology, CAD(Computer-aided Diagnosis) System resulting from the combination of information technology and medical imaging technology plays a more and more important role in detecting and treating cerebral vascular disease, and it has already become a research focus in medical imaging.

The cerebral aneurysm usually was located in the bifurcation position of vessel, especially the cerebral artery circulus, and the reason is that the impact of blood flow has great influence on the bifurcation position. Cerebral vascular image is similar to river network, and there exists artery and many other branch vessels. Generally, vessel is approximately symmetric, whose two edge contours are approximately mutual parallel. But cerebral aneurysm is the projecting part of the vessel edge caused by lesion. The schematic diagram of cerebral aneurysm is showed in Figure 1.

From Figure 1, the position marked by pane is cerebral aneurysm. The projecting part has appeared in the normal vessel and the approximately parallel of two edge contours is broken. The lesion site was manifested as obvious branch structure. So we can ascertain the lesion site of cerebral aneurysm by detecting the branch structure in vessel skeleton tree.

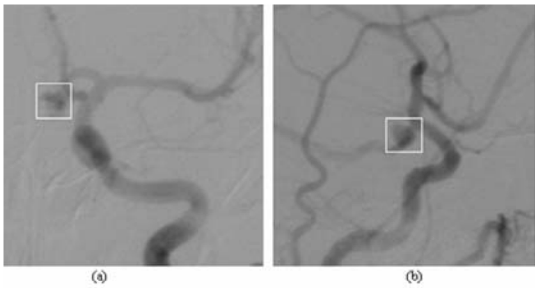

Figure 1. The schematic diagram of cerebral aneurysm

In the cerebral aneurysm CAD system based on DSA(Digital Subtracted Angiography), it is the premise and important step of feature extraction and recognition to detect the position of cerebral aneurysm in DSA. This paper analyzes morphological characteristics of cerebral aneurysm, obtains the topological skeleton tree via the improved thinning algorithm, then does depth-first traversal search on skeleton tree, and lastly detects the position of cerebral aneurysm.

II. OPTA ALGORITHM

OPTA(One-pass Thinning Algorithm) is a typical template-based image thinning algorithm, whose core is thinning processing by the application of elimination template and preservation template. OPTA is an iterative process. If the current point satisfies the elimination template and doesn't satisfy preservation template, it will be eliminated. Otherwise, it will be preserved. The original image is traversalled continuously until no point satisfies the above condition.

The main improvement upon OPTA is proposing new elimination template and preservation template according to the defect of thinning effect and thinning speed of original algorithm. Among them, the most typical documents are [1~3]. It is found by the authors of document [1] that original OPTA has the disadvantages of incomplete thinning, more burr and inadequate smooth. Much improvement has been undergone on elimination template and preservation template in the improved algorithm. Figure 2 and Figure 3 are the improved elimination template and preservation template respectively, among which shadow pane is current point.

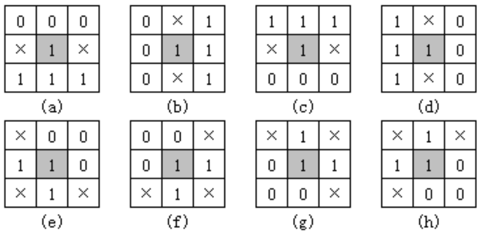

Figure 2. The elimination template of document [1]

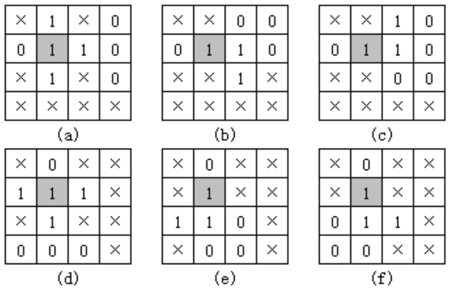

Figure 3. The preservation template of document [1]

Because the condition for preservation template in the algorithm of document [1] is too loose, the effect of right oblique line produces easily while analyzing the images, which made iteration times increase and the speed slow. Therefore, new preservation template was proposed on the basis of document [1] and they were increased to 9. From Figure 4, the condition of preservation template becomes more strictly, which solved the effect of right oblique line well, and the speed has been improved immensely.

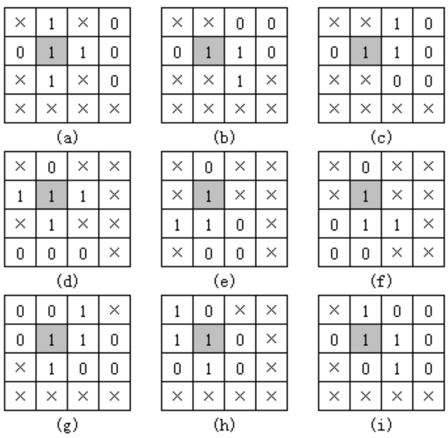

Figure 4. The preservation template of document [2]

With the development to the depth, Mei Yuan and other authors found that the effect of right oblique line was solved well by the algorithm of document [2] and the speed has been improved immensely. But because of its enhanced preservation condition, the breakpoints appeared. As a result, the topology and connectivity of original image has been destroyed and the thinning effect decreased. On the basis of the above analysis, Mei Yuan and other authors proposed the concept of composition template, which took advantage of the elimination template of document [1], abandoned the preservation template and combined the judgment whether the point satisfied the elimination template will be preserved with the situation of its neighborhood point. Figure 5 is the schematic diagram about the neighborhood of current point.

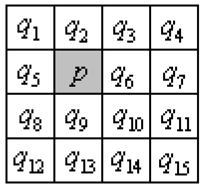

Figure 5. The neighborhood diagram of point *p*

The thinning algorithm based on improved composition template doesn't need matching operation for preserve template. Every elimination template corresponds to one case of every neighborhood points' pixel value, and it uses logical operation "&" and "||" to complete the judgment whether current point will be preserved. The following 8 conditions correspond to 8 elimination template marked with a~h in Figure2. If it satisfies elimination template and corresponding elimination condition, this point will be deleted. Otherwise, it will be preserved.

$$(q_4=0\&q_5=0\&q_6=0\&q_7=0)\,\|\;(q_5=1\&q_6=1\&q_{12}=0\&q_{13}=0\&q_{14}=0) \quad (1)$$

$$(q_2=1\&q_4=0\&q_7=0\&q_9=1\&q_{11}=0)\,\|\;(q_2=0\&q_9=0\&q_{12}=0\&q_{13}=0) \quad (2)$$

$$(q_5=0\,\&\,q_6=1\,\&\,q_7=0\,\&\,q_{11}=0) \quad (3)$$

$$(q_2=0\,\&\,q_9=1\,\&\,q_{13}=0\,\&\,q_{14}=0) \quad (4)$$

$$(q_8=1\,\&\,q_{10}=0\,\&\,q_{13}=0\,\&\,q_{14}=0)\,\|\;(q_8=0\,\&\,q_{10}=1\,\&\,q_{12}=0) \quad (5)$$

$$(q_3=0\,\&\,q_4=0\,\&\,q_7=0\,\&\,q_{10}=1)\,\|\;(q_3=1\,\&\,q_7=0\,\&\,q_{10}=0\,\&\,q_{11}=0)\,\|\;(q_8=1\,\&\,q_{10}=0\,\&\,q_{13}=0\,\&\,q_{14}=0)\,\|\;(q_8=0\,\&\,q_{10}=1\,\&\,q_{12}=0\,\&\,q_{13}=0) \quad (6)$$

$$(q_3=0\&q_4=0\&q_7=0\&q_{10}=1\&q_{11}=0)\,\|\;(q_3=1\&q_7=0\&q_{10}=0\&q_{11}=0) \quad (7)$$

$p=1$ (always holds, eliminate directly) (8)

Among them, *p* is the current point and Figure 5 shows $q_{1\sim15}$. Though at present, improved OPTA is only applied to the thinning of fingerprint image [4~8]. This paper applied the above and improved OPTA to skeleton extraction of cerebral vascular image. By many experiments, we found that the burr of vascular skeleton extracted by original OPTA is a bit more, so it cannot be used in the detection of cerebral aneurysm. The effect of document [1] is much better, but the thinning speed is not ideal. Though the thinning speed of document [2] was increased significantly, the breakpoint phenomenon produces easily while thinning vessel. Through weighing various factors, we determine that our work of extracting cerebral vascular skeleton was carried out on the basis of improved OPTA using composition template. The vascular skeleton gained by this algorithm has high quality; meanwhile, the speed is also enhanced.

III. Detection of Cerebral Aneurysm Based on Skeleton Tree

After obtaining the skeleton tree by thinning the cerebral vascular image, a certain width of the blood vessel becomes only a pixel width of the skeleton and cerebral vascular image becomes a curve of single pixel. Through the extraction of skeleton structure elements, the detection of cerebral aneurysm is based on the length of branch element on skeleton tree.

A. Extraction of Skeleton Structure Elements

1) Extraction of key point element

Key points present to the places where dramatic changes have been taken place in skeleton characteristics, which includes endpoint and bifurcation. Endpoint is the starting point on the part of skeleton tree, and p is endpoint if there has only one skeleton point in the eight neighborhood of the current point p, just as a,c,d and f shown in Figure 6. Bifurcation is the converging point of different parts of skeleton tree, and p is bifurcation if there has three or more skeleton points in the eight neighborhood of the current point p, just as b and e shown in Figure 6.

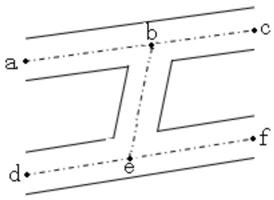

Figure 6. Skeleton structure elements representation

2) Extraction of branch element

Branch element is the skeleton segment, which connects two key points and does not pass by the third key point of the skeleton. If the key points are not endpoint, it is called inner branch, otherwise, outer branch. In this paper, branch element we discussed is outer branch. The extraction method of branch element starts with endpoint: Find a endpoint firstly, and track it along until the next point is bifurcation. The skeleton segment which starts with endpoint and ends with bifurcation is the branch element.

B. Detection of Cerebral Aneurysm Based on Branch Element

A conclusion gained by analyzing the morphology of cerebral aneurysm: how to detect the branch structure of cerebral vascular skeleton is the key to the detection of cerebral aneurysm. There are three kinds of branch structure of skeleton map which are caused by cerebral aneurysm, burr and normal blood vessels respectively. So cerebral aneurysm can be detected from the three kinds of branch structures by judging branch structure caused by cerebral aneurysm. In this paper, by doing depth-first traversal search on skeleton tree, the pixel length of branches will be the basis of detection.

The specific steps was conducted as follows.

(1) Traverse the entire skeleton tree from the root of skeleton tree, and mark the pixels which have been visited;

(2) Once encountering the bifurcation point P, visit each adjacent point of its 8 neighborhood in anticlockwise order from the vertical direction and put the points which are not visited into stack;

(3) Retrieve an element from the stack as a beginning point, continue to traverse pixels of skeleton tree with the above method, until there is no point that can be visited. Simultaneously use variable S to count the pixels which have been visited from the beginning point to the end. If the S is more than threshold T_1 and less than threshold T_2, the location of the curve is the part of cerebral aneurysm, and it can be considered as burr if S is less than T_1, normal blood vessels branch if S is more than T_2;

(4) Repeat the above process until the stack is empty. Then the cerebral vascular skeleton tree traversal is finished.

During the above process, the extraction method of bifurcation position is central with this point to examine the number of 8 neighborhood pixel point that is the objective and wasn't visited. According to empirical value, T_1 is set to 8 and T_2 is set to 16, which can eliminate the burr to some extent and the interference to the detection of cerebral aneurysm from normal vessel branch. This can obtain the best effect.

IV. Experiments And Analysis

The hardware environment used in the experiment is CPU: P (R) 4 2.8GHz; Memory: 512 M; display card: 128 M. The development environment is VC 6.0. Experimental data of cerebral vascular DSA images, whose format accords with DICOM 3.0 standard, are provided by the First Affiliated Hospital of Suzhou University. By using DICOM software developed by our institute, each DSA image is divided into DSA image sequences, which are saved as BMP format.

In the experiment, we do binarization segmentation on original images Figure 1(a) and Figure 1(b) firstly, then obtain its skeleton by using improved thinning algorithm, and detect the skeleton map using the cerebral aneurysm detection method based on the branches of skeleton map, lastly mark the suspected region of cerebral aneurysm with pane. The vascular structure of original cerebral vascular image in Figure 1(a) is relatively simple, and the image edge is smooth after binarization segmentation, which shown in Figure 7(a); while in Figure 1(b) the complexity and fuzziness of vascular structure causes the inadequate smooth and noise jamming of blood vessel after binarization segmentation, which shown in Figure 7(b).

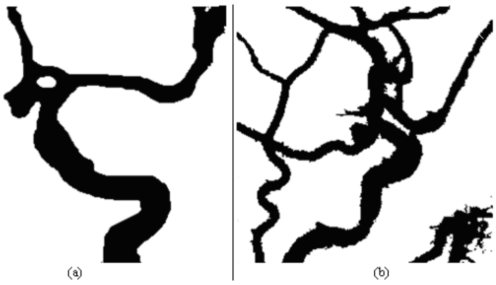

Figure 7. The effect diagram of the original image after binarization segmentation

Figure 8 is the final effect diagram of skeleton extraction and cerebral aneurysm detection method based on skeleton features.

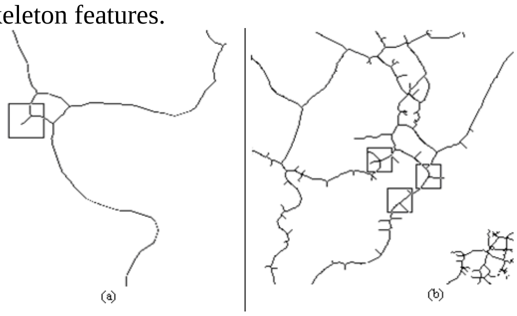

Figure 8. The effect drawing of cerebral aneurysm detection

This paper adopts the thinning algorithm based on improved composition template to extract the skeleton of binary image, which can effectively overcome the emergence of burr. It's a better-performing algorithm, but the contrast in the experiment appears different effects of skeleton extraction, Figure 8(a) with less burrs of skeleton, while Figure 8(b) with more burrs in skeleton. After a large number of experiments, the reason is found that the emergence of burr is largely due to the inadequate binary effect of blood vessels, noise jamming and other reasons. Burr in the vascular skeleton structure also manifested as the same branch structure, so it affects on the precision of cerebral aneurysm detection greatly. As shown in Figure8, the position marked by pane is the detected cerebral aneurysm part. The detection effect in Figure8 (a) is good, while two wrong regions exist in Figure 8(b).

In this paper, the cerebral aneurysm detection method based on skeleton features can basically determine the position of cerebral aneurysm. Although the length of branch used as a basis will encounter the interference of skeleton burr and exist incorrect detection, the significance of cerebral aneurysm detection is to reduce the numbers of detection objectives of cerebral aneurysm and provide data premise for recognition. How to do binarization effectively, provide best foundation to skeleton extraction, and reduce adverse effect on cerebral aneurysm detection caused by burr will be the future research emphasis.

V. Conclusion

This paper analyzes the morphological characteristics of cerebral aneurysm, researches OPTA and its improved algorithms deeply and applies them to the extraction of skeleton image successfully. A detection method of cerebral aneurysm based on skeleton is proposed, which detected cerebral aneurysm by the length of branch element. Experimental results show that the regions of cerebral aneurysm can be detected by this method after the extraction of branch elements on skeleton map. Furthermore, the accuracy of detection is affected by the effect of cerebral vascular segmentation and the extraction of skeleton. How to overcome these shortcomings and improve the success rate of detection is the focus of future works.

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