A 3-D Modeling Scheme for Cerebral Vasculature from MRA Datasets

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Abstract

This paper proposes an integrative approach that facilitates physicians to semi automatically obtain a 3-D symbolic representation of cerebral vasculature from 3-D magnetic resonance angiography (MRA) datasets. In this approach, firstly vessels are segmented by morphology method followed by 3-D parallel thinning to obtain the one voxel wide skeleton. Then a novel method employing general tree and its combinations is introduced to depict the 3-D geometrical structure of the vasculature. With the generated tree, post processing, such as traversal and visualization, is implemented. The method has been tested on both synthetic images and real images; the results are promising. A system based on this approach provides a useful visualization tool of the intracerebral vasculature for clinic applications.

1. Introduction

Accurate description of vasculature structure plays an important role in many clinical applications, e.g., for quantitative diagnosis, surgical planning, and monitoring disease progress or remission etc. However, due to the complex nature of vasculature structure, depicting it proves to be a difficult task. Three types of medical images are commonly used to provide vascular information: MRA (CTA), DSA and 3-D DSA. Visualizations acquired through these methods themselves are based upon image intensity values and can not provide direct 3D information about vasculature [1]. However, with the advancement of MRA acquisition technology, rapid and noninvasive 3-D mapping of the vascular structures are available. It has been an active research topic to represent the 3-D geometrical structure of the vasculature accurately and efficiently. Many researchers focused on central vessel axis as basis for the description to enable the physicians to obtain quantitative representation of the vessels of interest[2].

E.Bullitt et al. [2] proposed a method of producing directed graphs of the intracerebral vasculature from segmented MRA data. The accuracy of nodal connections was evaluated by registering a 3D vascular tree with DSA images obtained from the same patient. Gerig G. et al. [3] presented a prototype system that extracted 3D curvilinear structures from MRA and converted them into a symbolic description. A multi-step processing scheme is adopted, which included segmentation, binarization of volume data, skeletonization by binary thinning, and graph description of object structures. However, currently proposed methods all use directed acyclic graph to represent the vasculature, which is not the structure of vasculature in nature. Although easier to implement, due to the complex structures of vasculature it is difficult for these methods to eliminate the spurious vessels produced by noise. To solve this problem, we proposed an approach using general tree, which is more like human vessel in nature, to represent the vasculature. Satisfactory results are gained by applying our method on clinical images.

This paper is organized in the following way. The theoretical framework of the approach is discussed in section 2, together with the related works. Section 3 demonstrates our design, including pre-processing, tree generation, pruning and foresting. Evaluation results on clinical MRA datasets are provided in section 4. In section 5 we briefly discuss our method and give further research directions in the future.

2. System framework

The systems proposed by most researchers have basically the same data processing pipeline shown in fig 1. The differences lie in the particular algorithms adopted respectively.

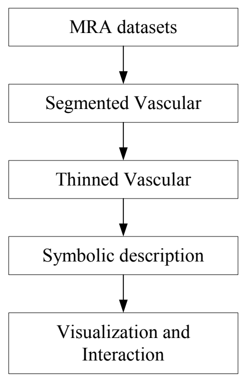


Figure 1. The framework of the state-of-the-art systems

Data structure is very important in algorithm design and implementation. Tree structure is an important data structure. It provides both efficient access and update to a collection of data and it is quite useful to represent hierarchical data. With knowledge that a cerebral vasculature is a binary tree in nature, it is intuitive to use binary tree to represent it. However, due to the complex structure of vasculature and the inevitable noise in MRA datasets, modeling the vasculature to simple binary tree works not well in realistic applications. To alleviate the limitation, we build a general tree model instead to depict the vasculature, which is more fitted and easy to realize operations needed.

There are several implementations to represent the tree, for instance, “List of Children”, which stores with each internal node a link list of its ordered children from lift to right. ”Left child right sibling”, in which each node stores its value and pointers to its parent, left child, and right sibling. Another representation is called “dynamic node”, in which variable space is allocated for each node [4]. Some other kinds of trees are used in image processing to describe the geometrical distribution of an image, such as qudtree and octtree. In our system “Left child right sibling” implementation is used. The node structure is shown in figure 2.

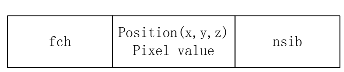
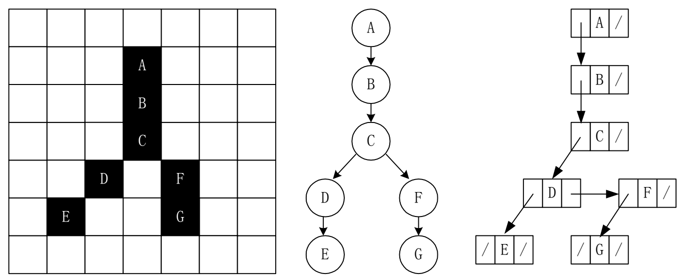


Figure 2. Data structure of the node of general tree

in which fch is the first child, nsib is the right sibling. The general tree with this node structure to represent the vasculature is called feature tree in our system.

Using this kind of data structure, we can represent the image in figure 3A as a tree in figure 3C. We classify the nodes (except the root of the tree) into three categories: the end nodes, whose fch and nsib are both NULL, the branch nodes, whose fcb and nsib are neither NULL, and the middle nodes, whose fch is not NULL, but nsib is NULL. The links between two nodes model the vessel segments.

The algorithm for the tree generating will be discussed in section 3.2.



A B C

Figure 3. A simple tree example represented by "Left child right sibling".
A: a binary image. B: symbolic representation of A. C: The general tree of A.

3. System Design

3.1 Pre-processing

The original MRA images not only contain vascular information, but also a lot of noise caused by the surrounding soft tissues. In order to depict the vasculature accurately, we must first segment the vessels from the background of original gray-level data.

The Gamma value and brightness of each MRA image is modified manually in advance to improve the contrast in gray-scale between vessels and tissues. Afterwards, thresholding is applied to binarize images.

Thinning on binary images is an iterative process which erodes an object layer by layer until only the skeletons of the objects are left [5]. The process must concern the geometry preservation and connectivity preservation. 2-D thinning is studied widely and rather satisfied results can be got quickly, but 3-D thinning is much more difficult because of huge data volume. Parallel 3-D thinning is studied extensively nowadays due to its fast speed, in which several simple points can be deleted in one iteration. E.g. in the method proposed by Ma et al. [6], four subsets of templates are used to delete simple points. Although the connectivity preservation of this algorithm was proved, the object can not be maximally thinned.

Palagyido et al [7] proposed a new parallel 3-D thinning algorithm in which maximal thinning can be realized. He used directional strategy in which each iteration step contains 12 successive parallel reduction operations according to 12 directions. 14 templates are identified in each direction. The templates of each direction are derived from rotation and reflection of templates of another direction. Boolean functions of 26-variables are used to ease the computation intensity. In this paper, Palagyido's method is adopted. Maximally thinned 3D vascular structure is obtained. Now we can go on to represent it using tree.

3.2 Tree generation

The geometry and the topology information of the vessels are coded by the symbolic representation with general trees in our system. There are many standard algorithms to generate a general tree in literatures. Some modifications are made to the classical algorithm to obtain the vasculature feature tree. We refer end nodes as those having only one object point in its neighborhood and branch nodes as those having three object points. The algorithm is shown as follows:

1) Choose a root, and assume it as current point. The root must be an end point which means there is one and only one object point in its neighborhood. E.g. in figure 3 A,E,G all can be treated as root. We select one point from them arbitrarily, say point A.

2) Set the pixel value of the selected current point to 0, which means it has been processed. In other words, it belongs to the background from now on and not the object any more. If there is no object point found, the algorithm terminates.

3) For each object point in current point's neighbor, allocate a new node for it and link it to the existing tree using the following procedure shown in the diagram:

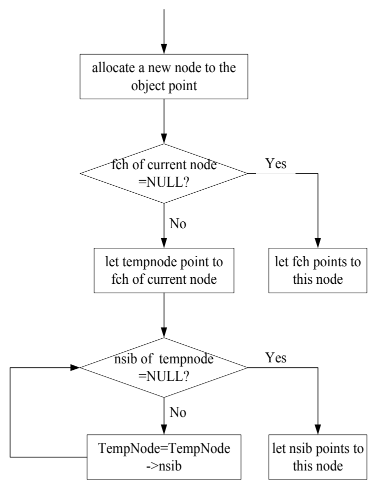


Figure 4. Algorithm flowchart of general tree generation

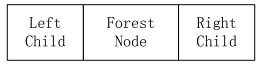
4) If there is any object point in the neighbor, turn to the step 5). Otherwise return to the outer layer of iteration, which is the parent point of the current point.

5) For every neighbor object point, return to step 2) to process. That means they will be treated as current point in turn and consequently their neighbor will be searched.

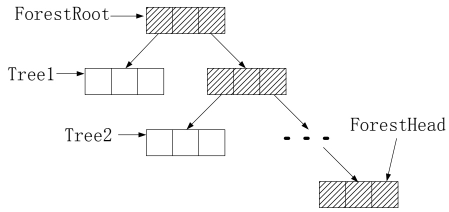
3.3 Post-processing

Pruning is the process in which trivial branches are removed from the tree while vessel axes are retained. Here the idea proposed by Peter [8] is applied, which is based on branch length measurement. Branches are discarded if they include at least one end point and have less length than a predefined threshed value. The length of each branch and whether it contains an end point are recorded during the traverse process in advance.

The output of the segmentation is a set of unbranched 3-D skeleton curves with an associated width at each point. As MRA datasets are noisy, the segmentation may include spurious vessels. It's neither feasible nor reasonable to represent them with a single tree because there are so many detached vessel segments exist. To solve this problem, foresting operation is introduced. Forest is a set of trees connected together. The data structure for forest is shown as follows:



A



B

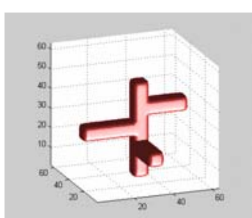
Figure 5. Data structure of forest. A: Node structure of forest
B: An example of forest; the forest nodes are marked by slash lines.

3.4 Visualization

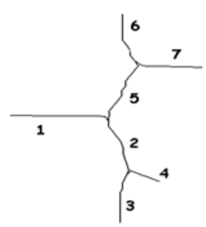
The results are visualized in by programming with OpenGL API[9]. The rendering process is much faster than the rendering of a whole 3-D data set due to great reduction of data amount. Interactive changes of viewpoints are offered to achieve better 3-D impressions. The user can pick up a vessel branch in the screen by clicking it, then the information of that vessel is displayed in the left bottom of the screen with its number, starting point and ending point, length, and to which tree it belongs, etc, shown.

4. Application results

Synthetic 3D data are used in our experiment to test the method. The workstation is Pentium 4 1.5GHz with 256MB RAM. Our test phantom and its topological model are shown in figure 6.



A



B

Fig. 6. Experimental result on Synthetic 3D data. A: The phantom shown in Matlab. B: The topological model of the phantom. It contains seven branches.

Clinical 3-D MRA images are also evaluated in the prototype system. During the traversal process, small trees with the number of nodes less than a given threshold were discarded since they probably represent noises in the dataset. In the figure, different colors represent different vascular trees. Figure 7a is the obtained MIP of a patient using Philips Gyroscan Intera. Figure 7b is the result using general tree with the same viewpoint.

A B

Figure 7. The vascular tree generated from MRA. A: the corresponding MIP of the same patient. B: the intracranial vasculature using general tree, which is displayed in our 3-D visualization and processing system.

5. Conclusions

In this paper the 3-D human cerebral vasculature is represented by general trees, which greatly facilitate the observation and operation of the vessels. Successful symbolic description of the vascular structure can contribute much for clinical diagnosis, planning and treatment. With similar framework as the state-of-the-art systems [2,5], we propose a novel representation of the vasculature using general tree which is most conform to the natural structure of intracranial vasculature, and many post processing such as traversal and pruning are done for physicians to analyze the vessels.

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