Acceleration of the Fully Automatic Branch Labeling of Voxel Vessel Structures

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Abstract. For diagnosing a stenosis or an aneurysm, the shape parameters of the diseased vessel parts are needed by physicians. Therefore, a fully-automatic extraction of this shape from a volume representation has been developed. This paper analyses the blood vessel branch labeling acceleration algorithms and proposes two improved methods. The first one is called the surface wave propagation method which restricts the wave moving along the blood vessel surface. The second one replaces the thinning algorithm with the surface propagation to extract the center lines and the bifurcations of the blood vessels. Experiment results show that two improved methods can decrease the computation time and keep the labeling accuracy.

1 Problem

3D Rotational Angiography system (3DRA) enables physicians to capture detailed 3D images of a patient vascular structure, which leads to faster and more accurate diagnosis and treatment. It is increasingly used to diagnose brain aneurysms, Gauvrit et al. [1], and to decide on the optimal treatment modality. Volume representations of blood vessels acquired by 3DRA after injection with a contrast agent have a clear distinction in gray values between tissue and vessel.

For optimal treatment, physicians need to know the shape parameters of the diseased vessels parts, Bruijns [2]. A method for fully-automatic labeling of blood vessels voxels has been developed by Bruijns[3]. This method starts with the detection of the extremities of the vessel by a wave propagation method by Zahlten et al.[4] in the segmented volume. The second step, a thinning approach is used to peel the blood vessels in a number of iterations. At last, the vessel vertices are labeled with a unique number for each vessel branch.

In this paper, we present two acceleration algorithms. First, we implemented a wave propagation confined to move along the blood vessel surface only (SWP). The second acceleration method replaces the thinning algorithm with the SWP to extract the center lines and bifurcations of the blood vessels.

2 Related Work On Branch Labeling

The graph structure can be generated by various skeletonization algorithms, which represents the topology of the blood vessels. Skeletonization methods based on morphological thinning are presented [5]. The topology conditions resulted occasionally in small cycles, which cannot be presented in the segmented voxel volume in their thinning method. A single skeleton is directly generated from the gray value volume [6]. But this method cannot be used for separated components. Since the vessel voxels cannot be labeled according to the branch or center region they belong to. A system for reconstruction of a vessel tree is created by a wave propagation (WP) [4]. The WP method labels the original gray value volume using an appropriate threshold and generates the corresponding vessel graph. However this method is not accurate enough at the bifurcations (Fig. 1(a, b)).

A method for robust mapping of bifurcating vessels is presented [7]. But a 3D triangle surface model of the vessel boundaries is needed as input for their computations. A thinning method is used after a wave propagation [8]. A segmented voxel volume with the extremities is set as the input data, the resulting skeleton of branches and bifurcations is a better approximation of the vessel graph than the method of Zahlten et al.. However the thinning is a time consuming approach for the bifurcation position correction.

3 Acceleration Methods of Branch Labeling

The branch labeling method consists of five main parts, and the first two of them are time consuming [8]. In this paper, the volume wave propagation (VWP) is replaced by the surface wave propagation (SWP). Then the first two steps are combined to one, the thinning processing is excluded. During the extremity detection, the center lines and bifurcations are extracted by the SWP.

3.1 Surface Wave Propagation

For the VWP, a wave consists of voxels which mostly form a cross section of the blood vessel. When the wave stops moving, a voxel could be found from the final wave, its distance to the seed point is the farthest. This voxel can be saved into an extremity set as an extremity. The extremities detection of the vessels inside

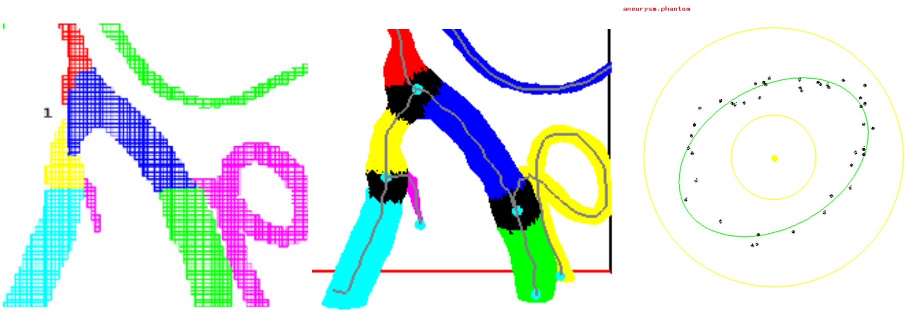

Fig. 1. Left: wrong bifurcation; middle: bifurcation position; right: fitted ellipse.

the volume is implemented by means of a wave propagation. The computing time depends mainly on the generation of a new wave from an old wave. When the inner vessel voxels can be ignored by giving them a special label, the waves will be much smaller because only the surface vessel voxels are included. In this case the waves will propagate along the vessel surface.

The starting point is a segmented volume with tissue voxels, aneurysm voxels and normal vessel voxels [9]. The initial wave was filled by the surface voxels after the selection of a seed point. During the double WG [8], all the neighbors of the old wave are found, in which only the surface voxels would be put into the new wave.

In the SWP, the center point of the stop wave could be set as the extremity for this branch. A false extremity would be detected by the original method when a cycle presents in the segmented voxel volume. In such a case the detected extremity is not at the branch tip. A yellow point labeled with "lost extremity" can be seen on the cycle in Fig. 2. A simple solution is to check whether all neighbors of the stop wave are tissue voxels. If any neighbor voxel has different branch number from the stop wave, it will be considered as a false extremity. In Fig. 2, the yellow and the cyan points indicate the extremities which are detected by the VWP and the SWP respectively; and the pink symbol means the detected results at the same voxel.

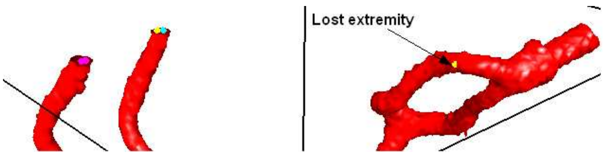

Fig. 2. The extremity detection comparison.

3.2 Center Lines Extraction and Bifurcation Detection

During movement of the wave, the center and the normal of a wave are used for the direction adjustment. The plane (a wave) should be orthogonal to the vessel. An oblique plane would give the wrong parameters such as a diameter.This section describes a method of fitting a plane to uncertain 3D points $\{P_i = (x_i, y_i, z_i)^T | i = 1...N\}$. All data points P_i that lie on the plane defined by the normal $n = (A, B, C)$ and the perpendicular distance to the original d. The value ϵ is introduced on the right of equation $Ax_i + By_i + Cz_i - d = \epsilon_i$ standing for the fitting error. The plane normal n gives the homogeneous least square problem,The solution is computed by means of singular value decomposition. In the same way, a least-square ellipse is directly fitted through a number of 3D points in a wave for the visualization. As shown in Fig. 1(c, a) yellow center and a green fitted ellipse indicate a wave.

Generally, bifurcations can be found when the wave is separated to two or more new waves. In this paper, the bifurcations can be positioned at where

Table 1. Statistical result of the volume and the surface wave propagation. For the decreased time, we obtained: min = 24%, max = 82%, mean = 50%, and std = 0.29.

Images	Extremity	Elapsed	False Ex	Lost Ex	Decreased time
ane p	7, 6	0.66, 0.37	1	0	44%
sten-1	22, 22	0.33, 0.18	0	0	45%
sten-p	51, 49	0.29, 0.19	3	1	36%
lane02	55, 53	48.5, 15.3	12	18	68%
lane50	163, 180	7.23, 4.76	46	11	34%
lane52	81, 68	36.4, 11.3	18	5	69%

the ellipses disconnect each other and defined as two main types. When the wave moves from a wider vessel to two or more narrower vessels, the wave could be disconnected. In this case the current wave center is defined as the type I bifurcation position. Conversely, when the wave moves from a narrower vessel to a wider vessel, the location where are the disconnected waves should be defined as the type II bifurcation. In Fig. 3(a), the gray parts indicate the bifurcation type II and these black symbols circle the bifurcation positions.

4 Experiments Results and Validation

The SWP has been applied for fully-automatic branch labeling algorithm [8] to 60 clinical volume datasets. Compare to the VWP, the computation time is decreased at least 24 % and at most 82 %. Parts of the validation result is given in Tab. 1. The size of the first three images is 128×128×128 and the others are 256×256×256. The extremity amount, the elapsed time and the amount of

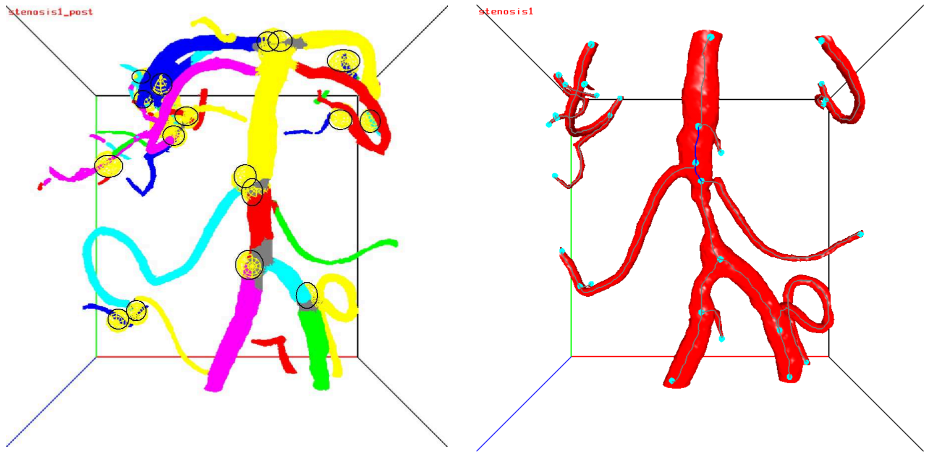

Fig. 3. (a) the bifurcation detection;(b) the labeling result.

the false or lost extremity are given in tab. 1. The two numbers in each grid of the first two columes are calculated with the methods bases on the VWP and SWP respectively. There are eight datasets have been manually tested for the bifurcation detection. Almost all bifurcations can be detected, which are indicated as the black symbol in Fig. 3(left). At last the labeling result is shown in Fig. 3(right).

5 Discussion and Conclusions

The following conclusions can be drawn from the results, the figures and the experiences gathered during testing. SWP always gives the correct and visually acceptable extremity detection results. The comparison result with the VWP shows that the detection time is decreased at least 24 % and at most 82 %. The centerlines and bifurcations extraction by SWP give the correct and visually acceptable results. Based on the extremity set, the center voxels set and the bifurcation set, the vessel graph is created but it needs to be evaluated. Whether the branch labeling result, generated by SWP based on a vessel graph, are suitable for computer assisted diagnosis has not been investigated yet.

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