A Semi-Automatic Centerline-Growing Method for Accurate Determination of the Local Vessel Orientation from Low Signal-to-Noise 3D Angiographic Images

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Introduction:

Centerline determination is an important step for mathematical modeling of blood vessels. In certain applications, such as the measurement of magnetic susceptibility between the blood and the background tissue [1], it is critical to determine the local vessel orientation accurately. Although many vessel extraction techniques have been developed [2], this particular need has not been sufficiently addressed. We have developed a least squares method that is accurate for orientation determination, easy to implement and very robust for low S/N ratio images.

Methods and Material:

The vessel centerline is extracted in several steps. (1) A spherical sub-region in the angiogram image is selected by the tracking program or by hand to center on a section of the blood vessel. The radius of the sphere is usually 2 to 5 times of the vessel diameter. (2) Image intensity data in the sphere are fit to a rod shaped object to determine its center position, orientation and diameter. The intensity I of the rod shaped object follows Gaussian distribution as below:

$$I = P * e^{-r^2/2\delta^2}$$

Where P is intensity, r is distance to the centerline of the rod, and δ is the width of the rod. There are six parameters in three-dimensional least squares fit program to determine direction, center, peak-intensity and width of the rod shaped object. When the direction of rod rotates to the true direction of local vessel in an image, the error function reaches the minimum, which tells the least squares fitting routine to stop. Now the centerline of the rod shaped object represents centerline of the local vessel. In the curve fit, the center point of the rod shaped object is constrained to move in the central plane perpendicular to initial rod direction. (3) Next center of the sphere sub-region will be selected along the resulting centerline and three pixels away from the previous center. (4) This process continues until the direction change from that of the initial point is more than 90^o or central displacement is more than radius of the sphere. Dedicated computer software was developed to implement this algorithm. Default parameters in the program are P=3000, δ=4 voxel units and radius of sphere=6 voxel units.

To evaluate the accuracy of this approach, we generated a synthetic test image with high noise level. The test image contained two concentric circular tubes with different circle size and tube radius. The large one had circle-radius of 80 pixels and tube-radius of 4 pixels, while the small one had circle-radius of 60 pixels and tube-radius of 1.0 pixel. The signal-to-noise ratio on both tubes decreased along the centerline from 3.0 to 0. This centerline extraction method has been also tested on a MRI image acquired from one element of Philips SENSE-body coil. This MRI image had inhomogenous intensity due to the surface receiver coil. The centerline extraction program was run on Sun Blade 1000 workstation.

Results:

Figure 1(left) shows synthetic test image with high noise level. Figure 1(center) shows that this method can extract the centerline with signal-to-noise ratio down to about 0.3. The tracking speed is about 20 points/second. Figure 1(right) shows the densitometric profile from bottom to top along diagonal line in figure 1(left). Figure 2 shows that this method has no difficulty to extract the centerline of an angiogram with the inhomogenous intensity.

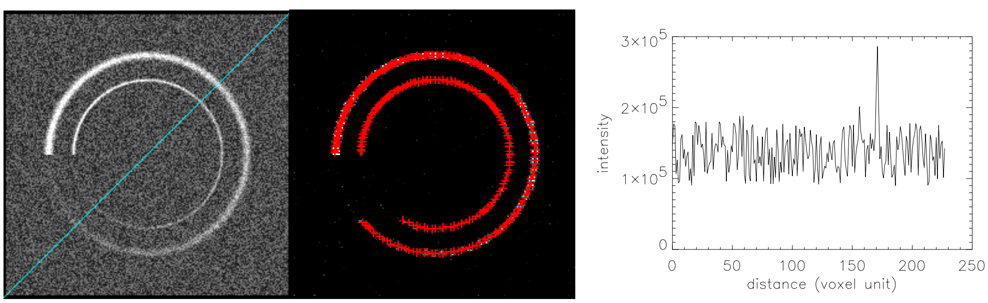

Figure 1: (left) Synthetic test image of concentric rings of different widths with additive noise, and signal is attenuated along the ring. The diagonal line is for profile plot. (center) Result of centerline extraction. (right) Densitometric profile along the diagonal line in the left figure.

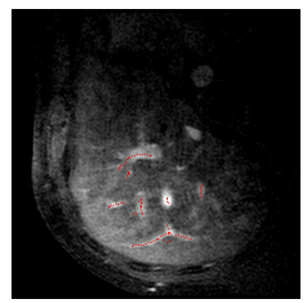

Figure 2: Hepatic volumetric MR image from one element of Philips SENSE-body coil.

Discussion and Conclusions:

In the paper, a novel and accurate method is presented to find the local vessel-direction using a 3D least squares approach. Based on the local direction of vessel, the centerline of vessels in a volume image can be extracted using the seed-growing method. Like the tube-like object detection approaches [2] and generalized cylinders model [3], our method also detects a special object but using different parameters and in different way to determine those parameters. The whole extraction process is also similar to the Ridge-Based approach [4] and shares the same advantage such as invariance to a wide range of noise. However, instead of the *cores*[5] method, the least squares approach was used to find the orientation and position of a rod shaped object in an angiogram image, which makes this new method more simple and easy to apply.

This method is robust in extracting the centerline on an angiogram image with low SNR and inhomogenous intensity. It is because direction of vessel is determined by all points in the spheral volume instead of only small portion of it such as surface. However, our program is not fully automatic at current stage. User has to manually insert seeds and remove some over-tracking points at the end of a branch. In the future, efforts will be made to automatically select seeds by a matched filter and automatically join vessel branches together using the 3d least squares fit on a fork-shape object model.

References:

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