Fast Contour Extraction in High Resolution In Vivo Rat Spinal Cord MR Images

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Introduction

Accurate spinal cord contour extraction is important in quantitative assessment of atrophy [1], lesion detection in spinal cord related diseases, and registration of multi-modal spinal cord MR images, such as T1/T2/PD weighted, fMRI, and DTI images [2], for comprehensive study of physiologic and pathologic changes following spinal cord injury. In this paper, we present a new B-spline snake [3] based technique for fast unsupervised spinal cord contour extraction from high resolution *in vivo* rat spinal cord MR images.

Methods

Imaging: In vivo spinal cord images were acquired on three normal rats on a Bruker 7T MR scanner. An inductively coupled coil was implanted in the dorsal part above the spinal cord and centered at T7 segment to improve the SNR. The T7 spinal processes of all three rats were surgically removed before imaging to create internal landmarks for localization of image planes. Eight oblique axial slices were prescribed perpendicular to the spinal cord around T7. All three rats were scanned using a fast spin echo sequence with respiratory gating. Imaging parameters were: TE/TR = 26/1500ms, echo train length 4, FOV (2 cm×2 cm), slice thickness (1 mm), matrix size (256×256), and number of averages 8. The in-plane resolution was 80×80 μm^2. Total imaging time for one rat was about 20 minutes.

Contour extraction: The spinal cord contour was modeled using a B-spline snake defined in polar coordinate system. Compared to conventional B-spline snake parameterized in Cartesian coordinate system, the polar B-spline snake is more efficient in describing the shape of the spinal cord contour, which is approximately circular on axial images. The origin of the polar coordinate system was determined by the user-selected point around the central canal of the spinal cord only once on a single slice. It was the only user intervention required in the contour extraction procedure and can be set in a matter of seconds. The B-spline snake was initialized as a small circle centered at the origin, and deformed toward the spinal cord contour by minimization of the weighted sum of the external and internal energy of the snake. The external energy is defined as the square of normalized magnitude of the gradient of the image, which was computed using a Prewitt operator. It attracts the snake to the edge of the spinal cord. The internal energy is defined as the square of the curvature of the snake. It controls the shape of the deformed snake and prevents the evolution of sharp corners. The optimal control points of the snake were computed using a constrained non-linear optimization technique.

The accuracy of our unsupervised contour extraction technique was evaluated by comparing the computed contours to manually defined spinal cord contours. The difference in radius and enclosed area between the two contours was computed using 100 points uniformly interpolated along the circumferential direction of the spinal cord contours. To test the intraobserver and interobserver reproducibility, the contour detection algorithm was performed on the same set of images based on the origins determined by two independent users, and the resulting contours were compared with each other.

Results and Discussion

The polar B-spline snake contour extraction algorithm was implemented using MATLAB on a Pentium 4/2.8 GHz PC. In all experiments, a combination of cubic spline (order 4) and number of control points 14 was found to achieve a good balance between accuracy and speed.

Our unsupervised method took an average of 1.6 seconds per image to complete the contour extraction procedure. Figure 1 shows the origin, initial position of the polar B-spline snake and the detected contours in two spinal cord images. Table 1 and Figure 2 show the results of the comparison of detected and manually defined contours. For pooled data from all images, both contours showed good correlation in radius (r = 0.72, P<0.01) and enclosed area (r = 0.60, P<0.01). The relative difference of detected and user-defined contours were 1.08±7.61% and 1.96±3.61% in radius and area respectively. The results from the interobserver and intraobserver reproducibility tests, as shown in Tables 2 and 3, suggest that the above unsupervised technique was highly reproducible.

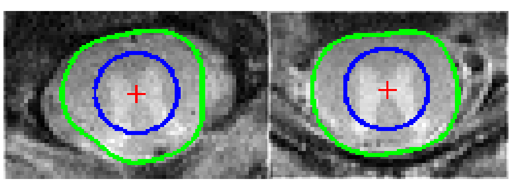

Fig 1. The origin (red cross), initial position of the polar B-spline snake (blue) and the extracted contour (green) in two high resolution in vivo rat spinal cord images

Table 1. Correlation coefficient and relative difference between contours from all images computed using our technique and user-defined contours.

	r	P	Relative Difference (mean ±SD %)
Radius	0.72	<0.01	1.08±7.61
Area	0.60	<0.01	1.96±3.61

Table 2. Correlation coefficient and relative difference between contours from all images in the interobserver test.

	r	P	Relative Difference (mean ±SD %)
Radius	0.89	<0.01	0.05±3.66
Area	0.84	<0.01	0.16±1.93

Table 3. Correlation coefficient and relative difference between contours from all images in the intraobserver test.

	r	P	Relative Difference (mean ±SD %)
Radius	0.91	<0.01	0.43±3.34
Area	0.84	<0.01	0.69±1.90

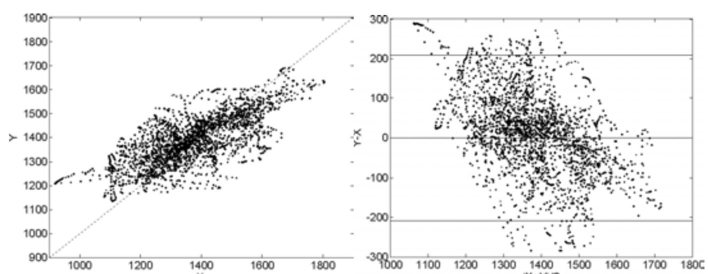

Fig 2. Scatter (left) and Bland-Altman (right) plots comparing radii of contours computed by our technique (Y) and user-defined contours (X). Unit in both plots is µm.

Conclusion

We presented a new unsupervised algorithm for contour extraction from high resolution in vivo rate spinal cord MR images. It is based on a B-spline snake defined in polar coordinate system, and can compute the contour in 1.6 seconds. Our experimental results from three normal rat demonstrated that the contours computed using our technique were highly reproducible and correlated well with user manually defined spinal contours.

Acknowledgement

This research is supported by NIH Grant # R01 NS030821 and NS045624

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