Automatic Cortex Extraction and Gray/White Matter Segmentation from T1-Weighted MRI with Geodesic Active Contours

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Introduction: An important biomarker for patients with neurodegenerative disease such as Multiple Sclerosis (MS) is tissue atrophy due to neural-axonal loss in the brain and spinal cord [1]. Thus, one important application of automatic brain extraction and tissue segmentation methods is to provide systematic and quantitative analysis of brain volumes from magnetic resonance imaging (MRI). Standard techniques such as Statistical Parametric Mapping (SPM) [2] and the FMRIB (functional MRI of brain) software libray tools (FSL) [3] have shown inconsistent results when applied to real MRI scans. In this paper we have developed a novel automatic brain extraction and segmentation method based on three-dimensional (3D) geodesic active contour evolution.

Method: Our method starts by correcting for existing bias fields with N3 correction [4] and improving the signal-to-noise ratio with an anisotropic diffusion filter [5]. The data is then pre-processed with a hybrid of mathematical morphology operations, connected component analysis, and thresholds based on the expectation-maximization (EM) algorithm. A geodesic active contour [6] is released in the pre-processed feature image, followed by morphology and thresholding refinement, and hole-closing operations. The resulting brain masks are then segmented into gray matter (GM) and white matter (WM) by incorporating voxel statistics and image gradient and curvature information into each tissue feature image for the evolving 3D active contours.

Data: Our tests utilized 18 synthetic T1-weighted volumes from the BrainWeb (http://www.bic.mni.mcgill.ca/brainweb) simulated brain database with 1mm×1mm×1mm in spacing. Noise level varied at 0%, 1%, 3%, 5%, 7% and 9%, and intensity non-uniformity varied at 0%, 20% and 40%. We also utilized 18 real T1-weighted volumes which were acquired coronally with 256×256×128 resolution and 1.5mm thickness from the International Brain Segmentation Repository (IBSR V2.0). The MR brain data sets and their manual segmentations were provided by the Center for Morphometric Analysis at Massachusetts General Hospital and are available at http://www.cma.mgh.harvard.edu/ibsr.

Results: We examined our GM and WM segmentation results both quantitatively and qualitatively by comparing with SPM2 and FSL.

TABLE I
AVERAGE PERFORMANCE OF 18 BRAINWEB DATA

Method	Metric	Brain (%)		Gray Matter (%)		White Matter (%)	
		Mean	*Std Dev*	*Mean*	*Std Dev*	*Mean*	*Std Dev*
SPM2	*Similarity*	*n/a*	*n/a*	*89.45*	*3.79*	*86.69*	*9.04*
	Sensitivity	*98.90*	*0.45*	*97.73*	*1.23*	*77.96*	*12.92*
	Specificity	*99.34*	*0.10*	*94.00*	*3.16*	*99.88*	*0.12*
FSL	*Similarity*	*n/a*	*n/a*	*88.04*	*2.01*	*88.42*	*5.09*
	Sensitivity	*99.61*	*0.05*	*91.31*	*1.28*	*80.68*	*7.90*
	Specificity	*97.43*	*0.23*	*95.42*	*1.66*	*99.73*	*0.27*
Proposed Method	*Similarity*	*n/a*	*n/a*	*88.79*	*4.13*	*92.95*	*2.33*
	Sensitivity	*99.26*	*0.10*	*88.61*	*6.93*	*91.12*	*1.22*
	Specificity	*99.30*	*0.11*	*96.98*	*0.24*	*99.00*	*1.19*

TABLE II
AVERAGE PERFORMANCE OF 18 IBSR V2.0 DATA

Method	Metric	Brain (%)		Gray Matter (%)		White Matter (%)	
		Mean	*Std Dev*	*Mean*	*Std Dev*	*Mean*	*Std Dev*
SPM2	*Similarity*	*84.89*	*6.87*	*69.12*	*9.27*	*65.22*	*17.86*
	Sensitivity	*80.38*	*7.25*	*67.99*	*7.57*	*55.23*	*18.26*
	Specificity	*9.33**	*12.47*	*58.28*	*18.35*	*93.98*	*6.40*
FSL	*Similarity*	*92.28*	*5.32*	*78.66*	*6.70*	*84.40*	*3.81*
	Sensitivity	*98.79*	*1.35*	*71.69*	*5.97*	*89.01*	*5.22*
	Specificity	*16.08**	*14.58*	*84.49*	*10.01*	*89.22*	*5.54*
Proposed Method	*Similarity*	*95.17*	*2.50*	*79.06*	*6.84*	*85.96*	*3.40*
	Sensitivity	*93.32*	*5.35*	*70.02*	*8.79*	*90.89*	*3.89*
	Specificity	*2.65**	*1.83*	*89.00*	*3.73*	*88.89*	*6.74*

** indicates false positive as a ratio of the true volume instead of specificity.*

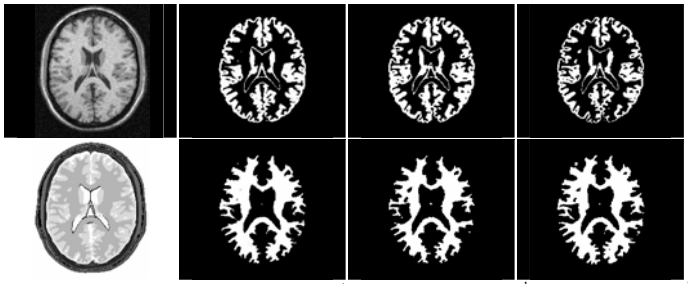

Fig. 1. BrainWeb data and phantom (1st column), SPM2 (2nd column), FSL (3rd column), and our results (4th column).

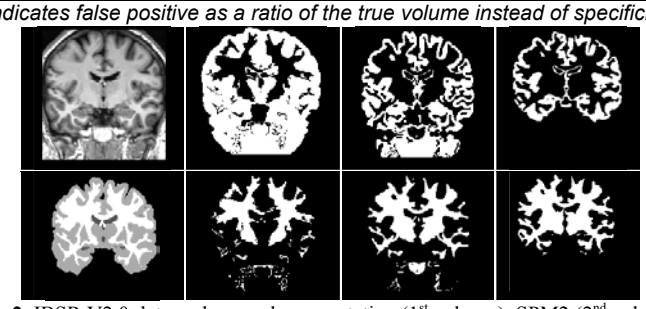

Fig. 2. IBSR V2.0 data and manual segmentation (1st column), SPM2 (2nd column), FSL (3rd column), and our results (4th column).

Discussion: With synthetic BrainWeb data, all three methods perform comparably in brain extraction and tissue segmentation. With real IBSR V2.0 scans, our initial brain extraction stage produces significantly better brain masks than SPM2. It also outperforms FSL in improving the similarity index and the false positive rate which FSL sacrifices for improving the true positive rate and sensitivity. Tissue segmentation performance degrades considerably for SPM2, whereas our proposed method remains robust and slightly outperforms FSL on average. The qualitative results with IBSR V2.0 data demonstrates that the brain extraction error propagates to the segmented tissue masks in both SPM2 and FSL.

References:

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