Semi-automated Volume Segmentation of the Brain Based on A Level Set Approach

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Introduction: Minimum-intensity projection (mIP) is commonly used in the display of 3D susceptibility weighted imaging (SWI) data because of the negative venous contrast in SWI [1]. Voxels in air and bone can be in the path of projection in the peripheral regions due to the natural shape of the brain. The low intensity in air or bone results in the loss of signal from veins and brain tissue in the mIP image in these regions. Manual segmentation of brain tissue is effective in avoiding the signal loss [2]. The manual segmentation procedure, however, is laborious and subject to human bias. In this study, we present the results of a semi-automated volume segmentation using a level set approach to obtain a brain mask using magnitude images.

Methods: SWI data were acquired on a GE 3T scanner with a size of 512x384x64 and TE/TR/α=20ms/34ms/20^o. The field-of-view was 26cm×19.6cm and the slice thickness was 1.0mm. Zero padding was applied along slice direction to obtain a matrix size of 512×384×128. Top and bottom 4 slices were removed to avoid wrap-around artifacts. A median filter (3×3×3) and a mean filter (3×3×3) were applied on 120 slices to suppress vessels and make brain area smooth. Binary g maps were obtained after thresholding the filtered images based on intensity histogram. The g values were used as edge indicators in the level set equation. Active contours C in level set formulation were represented by the zero level set $C(t) = \{(x, y) | \phi(t, x, y) = 0\}$ of a level set function $\phi(t, x, y)$. Initial rectangular contour $C(0)$ was placed inside the brain region in the mIP of the filtered magnitude images. Level set evolution was applied on the mIP image and to obtain a brain contour, which was used as $C(0)$ when applying level set evolution on all slices. The region surrounded by the $C(0)$ was defined as R. Initial level set function was defined as -4, 0, and 4 in pixels outside, on the boundary, and inside of the region R, respectively. The evolution equation of variational level set function of active contours without re-initialization [3] was written in the form: $\partial\phi/\partial t = \mu[\Delta\phi - div(\nabla\phi/|\nabla\phi|)] + \lambda\delta(\phi)div(g(\nabla\phi/|\nabla\phi|)) + \nu g\delta(\phi)$, where the first term was associated to the internal energy, which is crucial to keep the evolving level set function as an approximate signed distance function during evolution. The second and third terms in the equation correspond to the external energy, which can move the zero level curve toward the brain boundaries. The parameters μ, λ, υ were selected to be 0.04, 5, and 3, respectively. mIPs of conventional SWI with and without using the brain masks were both obtained. Hamming window size of SWI was selected to be 192x144.

Results: Figure 1a shows the mIP of conventional SWI. The white contour, as indicated by a short arrow in Fig. 1(b) is the level set segmentation based on one slice and the green contour, as indicated by a long arrow, is the initial level set contour for all slices. Figure 1c is the mIP of SWI images masked by level set volume segmentation. Figure 1d is the mIP of SWI images masked by manual volume segmentation. Signal loss in the peripheral brain regions in Fig. 1(a) was effectively avoided by applying the level set mask (Fig. 1c) and manual mask (Fig. 1d) prior to mIP. The semi-automated level set segmentation method provides comparable results as manual segmentation.

Discussion: The level set approach provides a feasibly solution for semi-automated volume segmentation of the brain with minimal human bias. Volume segmentation based on a level set approach can provide substantially improved visibility of the veins located in the peripheral regions of the brain with mIP display.

References: [1] Haacke EM, et al., MRM 2004;52:612-8; [2] Jin Z, Xia L, Du YP. JMRI 2008;28:327-33. [3] Chunming Li et al., CVPR 2005.

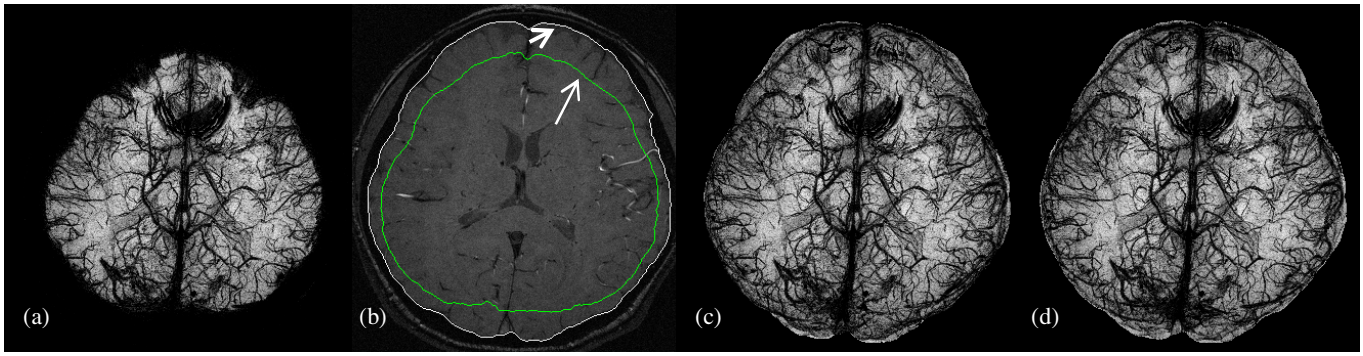

Fig. 1. (a) mIP of conventional SWI, (b) red contour is the level set segmentation of one slice and the green one is the initial level set contour, (c) mIP of SWI images masked by level set segmentation, (d) mIP of SWI images masked by manual segmentation.