

Robust Volume Segmentation Using Noise Statistics of Phase and Magnitude

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Introduction: Tissue-air volume segmentation (VS) is an important prerequisite for quantitative volume analysis or display of the brain in many applications. VS has shown to recover signal loss in the peripheral regions of the brain in minimum intensity projection (mIP) display of susceptibility weighted imaging (SWI) data [1]. Robust and automated tissue-air segmentation is highly desirable because manual segmentation can be laborious and inaccurate. Conventionally, only magnitude images are used in VS. In this study, a semi-automated algorithm using the statistical properties of both phase and magnitude in air and tissue is presented for robust tissue-air VS.

Methods: The tissue-air VS algorithm was based on the following hypotheses. First, the phase has a nearly uniform distribution between $-\pi$ and π in air and has a narrow distribution near zero in tissue. Second, the voxel intensity is much higher in tissue than in air. The standard deviation-to-mean ratio (SMR) in magnitude images was also calculated using the 27 voxels in the kernel and normalized to the SMR in air. First-order phase difference (FPD) was calculated in 158 combinations of voxel pairs in a 3x3x3 kernel to characterize local phase distribution without the need for phase unwrapping. The standard deviation of FPD (stdFPD) was calculated in 158 combinations of voxel pairs in the kernel and normalized to the stdFPD in air. The value of stdFPD is expected to be near zero in tissue and have a Gaussian-like distribution peaked at 1.0 in air. Another parameter defined as $\theta\text{FPD}=2C_{\text{out}}/N$, where N is number of FPD values calculated in the kernel and C_{out} is the count of FPD values in the sub-regions of $(-\pi, -\pi/2]$ and $(\pi/2, \pi]$, was calculated to characterize the “uniformness” of FPD distribution in the kernel. The value of θFPD was expected to be near zero in tissue and have a Gaussian-like distribution peaked at 1.0 in air. Local field gradient can introduce a linear background phase (LBP) in a kernel and elevate the calculation of θFPD and stdFPD in regions with severe field inhomogeneity, such as in the orbitofrontal cortex (OFC). LBP was estimated as the FPD along 13 discrete directions in a kernel and subtracted from the calculations of stdFPD and θFPD . A parametric map of $\Omega=\text{SMR}^*\text{stdFPD}^*\theta\text{FPD}$ was then constructed. The Ω map is expected to have a value near zero in tissue and a Gaussian-like distribution peaked at 1.0 in air. A binary mask for VS was obtained by applying a threshold to the Ω map. Since the skull has a Ω value similar to that in air, the brain tissue and scalp tissue are well separated in the binary map. A region growing algorithm was applied to the binary map followed by a dilation-erosion procedure to remove signal void in large veins.

Results: The proposed VS algorithm was applied to a 3D complex SWI dataset acquired with a TE=16ms at 3T. Fig. 1a shows the magnitude image in a slice near the Circle of Willis. Vascular structures have high values in the SMR map, as shown in (b). The stdFPD and θFPD maps are shown in (c) and (d), respectively, with elevated values at OFC, as indicated by the arrows. With the correction of LBP, the artifact at OFC was largely suppressed in the stdFPD and θFPD maps, as shown in (e) and (f), respectively. The Ω map, as shown in (g), has substantially improved tissue-air differentiation than any other maps. Excellent segmentation of brain tissue was obtained using a dilation-erosion procedure following the thresholding of the Ω map. The mIP of the 3D SWI dataset with and without VS is shown in (i) and (j), respectively. Veins in the peripheral regions of the brain are obscured in the mIP without VS and are well depicted in the mIP with VS.

Discussion: The use of statistical properties of noise in both phase and magnitude substantially improves the robustness in semi-automated tissue-air volume segmentation in the brain. Errors introduced by local background phase can be effectively removed in the calculation of stdFPD and θFPD . Venous vasculature in mIP images can be better visualized after applying VS to the 3D SWI data.

References: [1] Haacke EM, et al., MRM 2004;52:612-8;

Fig. 1. (a) the original magnitude image in a slice near the Circle of Willis; (b) the SMR map; (c) the stdFPD map with elevated values at OFC, as indicated by an arrow; (d) the θFPD map with elevated values at OFC, as indicated by an arrow; (e) the stdFPD map with correction of LBP; (f) the θFPD map with correction of LBP; (g) the Ω map; (h) the segmentation mask. (i) the mIP of the 3D SWI data without using volume segmentation; (j) the mIP of the 3D SWI data using volume segmentation.

