A Knowledge-Guided Active Model Method of Cortical Structure Segmentation on Pediatric MR images

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Introduction:

Although numerous studies of brain structure segmentation have been performed using either registration based or active model-based methods, most of these methods were extensively developed and validated primarily for adults and, to a lesser degree, children with normal-appearing brains. Furthermore, different studies have focused on different individual brain structures with few including all cortical structures, i.e. lobes, brain stem, and cerebellum. In this study, we proposed to develop a new knowledge-guided active model (KAM) method to segment cortical structures in the pediatric brain.

Methods:

A novel object function similar to the Gibbs free energy was defined. Segmentation was viewed as a procedure of minimizing Gibbs free energy. Triangular mesh models of cortical structures were affine registered to images of given target subject using an affine registration to maximize entropy, which was defined as normalized mutual information [1]. Then the registered mesh was actively slithered to boundaries of the structure by minimizing enthalpy. Enthalpy was defined as the sum of external energy, curvature energy, and continuity energy. The external energy was defined by the distances of the triangle vertex to the nearest edge of the given image: the longer the distance, the higher the external energy. The curvature energy was described by normal differences between triangles which share a vertex: the larger the difference, the higher the curvature energy. The continuity energy was defined by the length differences of edges which share a vertex: the larger the difference, the higher the continuity energy. The active meshes continue to adjust their vertex positions until enthalpy does not change. Ten cortical structures, including left and right (L/R) frontal lobe, L/R parietal lobe, L/R temporal lobe, L/R occipital lobe, brain stem and cerebellum, were segmented independently by KAM on MR images from a normal healthy child. The volumetric results and image similarities were compared with manual defined structures. Furthermore, the performance of KAM was compared with segmentation results using a nonlinear registration method provided by SPM2.

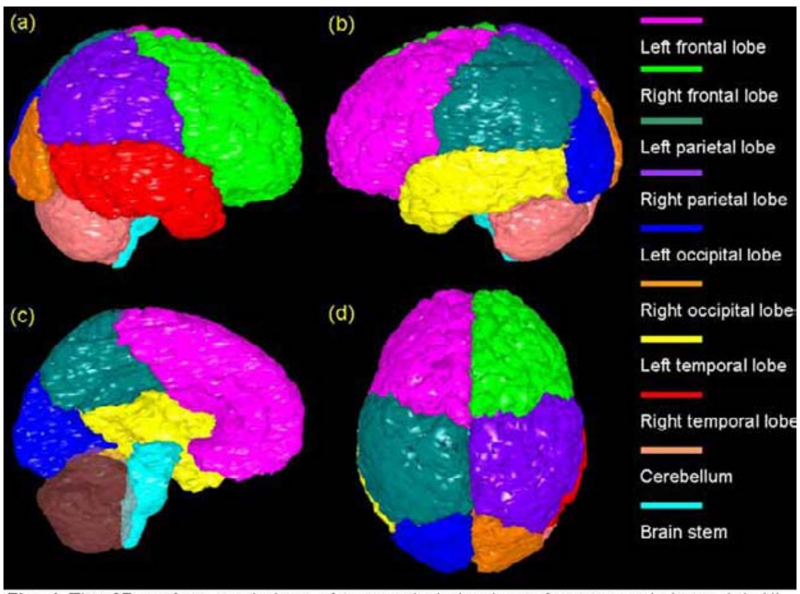

Fig. 1 The 3D surface renderings of segmented structures from several views. (a) All segmented structures in right view, (b) all segmented structures in right view left view, (c) segmented structures in left hemisphere in right view (cerebellum is set to semi-transparent for illustration brain stem), and (d) all structures in top view.

Results:

Fig. 1 illustrated segmentation of cortical structures using KAM. The average volumetric agreement between manual and KAM defined structures (95.36% ± 3.72%) was higher than that of manual and SPM2 defined structures (90.38% ± 7.42%). The average kappa index between the manual and KAM results was 0.95 ± 0.02. The average kappa index between the manual and KAM results was 0.86 ± 0.06. The kappa indices between manual and KAM defined structures were significantly higher than those between manual and SPM2 defined structures ($P \leqslant 0.001$, two tails).

Discussion:

In this study, we defined a new approach to overcome the intersubject variability, which is the most intriguing problem in automatic brain segmentation of MR images. Historically, the two types of segmentation currently available focused on only one component of this new approach, i.e. registration-based focused on maximizing the entropy; and ASMs and AAMs focused on minimizing the enthalpy. Both methods suffer from large morphologic differences between reference atlases and given target images. The new approach includes both energy terms so that maximizing the entropy compensates for the large differences between atlases and given images and minimizing the enthalpy locates the boundaries of structures.

KAM was used to segment 10 cortical structures on an independent MR data set from another normal healthy child. Manual delineation of all cortical structures is very time-consuming procedure. The tracing of these ten cortical structures on the images with 1mm × 1mm × 1mm resolution required at least 100 hours for an experience investigator. While preliminary, because the ten structures were segmented independently, these results do represent some assessment of robustness to structures of different size and shape but can not ascertain the true robustness of the approach across subjects with or without large morphologic differences. We do plan to evaluate the performance of KAM on another two subjects, and test its robustness on MR images from a large group of pediatric patients with brain tumors.

Conclusion:

In conclusion, we have developed a novel automatic algorithm, KAM, for segmentation of cortical structures on MR images of pediatric patients. Our preliminary results indicated that when segmenting cortical structures, KAM was in significantly better agreement with manually delineated structures than SPM2. KAM can potentially be used to segment cortical structures for conformal radiation therapy planning and for quantitative evaluation of changes in disease or abnormality.

Reference:

1. Maes F et al *IEEE Trans Med Imaging* 1997; 16: 187-98.