Evaluation of a level-set based method for brain surface mapping

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Objective

The level set method using implicit representation has recently been developed and shown to be capable of matching curves of different shapes as well as other types of geometric objects (Liao et al., 2003). The method was evaluated in this study for its ability to match sulci on flattened 2D brain surfaces of individual subjects to a population average set of sulci to provide a diffeomorphic warping of the brain surface. This is a key step in cross-subject brain image registration, allowing multiple subjects' data to be compared and integrated, after adjusting for gyral pattern differences. Prior deformation methods that involve matching equidistant landmark points along each sulcus using point matching techniques do not allow relaxation along each sulcus. Moreover, it is relatively difficult to incorporate these techniques into other methods due to the non-variational nature of point constraints. The method proposed by Liao incorporates infinite dimensional group actions into the level set method and offers a unifying approach for different types of feature-based matching. Thus, a diffeomorphic, one-to-one, and onto mapping can be generated using this approach, subject to different kinds of feature-based constraints.

Method

The surface of a brain hemisphere, as determined from high resolution MRI, was flattened to a 2D square (size 256x256) using the method by Thompson et al. 2002, and nine major sulci were traced (including the central, precentral, postcentral, middle frontal, primary intermediate, collateral, and olfactory sulci, an olfactory control line and the Sylvian fissure).

The traced sulci were discretized to a reduced grid space of 64x64. Two level sets were defined on the grid space such that the part of one level set that was enclosed by the other coincided with one or multiple sulci. Additional pairs of level sets were defined until all the selected sulci had been included. The boundary of the hemisphere at the interhemispheric midline was represented by a single level set. A similar procedure was performed to generate the level sets for the population average sulci.

Liao's level-set based method was then applied to match the sulci of the individual to the population average. The resulting diffeomorphic transformation (interpolated back to 256x256 size) was then applied to warp the flattened brain surface of the individual.

The procedure was repeated for the brain surfaces of 3 normal individuals, and the spread of the matched sulci was evaluated as a measure of the adequacy of the method. The mean difference from the average template curves was calculated by evaluating the signed distance functions of the average curves and the signed distance functions of the warped curves. All the warped brain surfaces were averaged together and compared to the population average brain surface.

Results

Liao's method was successful in matching the sulci of all 3 normal subjects to a population average set. The maximal spread of the matched sulci of 3 individuals was a mean .12 pixels different from the mean on a 256 by 256 grid. The appearance of the average brain surface (after warping) of these individuals was similar to the population average that was previously determined from 3 normal subjects.

Conclusion

Liao's level-set based matching method is capable of warping brain surface images to a population average, which allows brain imaging data from multiple subjects to be compared and integrated. The procedure is also expected to be useful for monitoring disease progression and for evaluation of treatment.

References:

[1]. W.H.Liao, Mathematical techniques in object matching and computational anatomy: a new framework based on the level set method, Ph.D. dissertation, UCLA, 2003.

[2]. P. Thompson and A. W. Toga, "A framework for computational anatomy," Computing and Visualization in Science, vol. 5, pp. 13-34, 2002.

Supporting data:

Figure 1a shows the 3D representation of the curves with the curves to be matched overlaid. Using the theory developed in [1], the curves in the 2D dimensional space are warped using diffeomorphic matching to the average curves. The theory is detailed in Liao (dissertation, [1]).

Figure 1b shows the individual curves on top of the 2D flattened brain surfaces. These curves fit exactly on top of the sulcal fissures in the flattened brains. Figure 1c shows the average curves on the individual flattened surface. Figure 1d shows the warped brain image with the average curves. The average brain curves fit into the grooves of the warped image where they did not previously. With the diffeomorphic matching technique, the 2D representation of the brain surface is successfully warped to the average curves, enabling precise cross-subject registration of brain data.