Layered Distance Map with Applications to Measuring Cortical Thickness and Reconstructing Cortical Surface

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I. Objective

Due to the advanced magnetic resonance imaging (MRI) techniques, MR images remain to be most useful for research into anatomical structures of human brains in vivo. Modern anatomical MRI studies on human brains have been concentrated on the cerebral cortex, which contains dense neurons and controls high cortical functions. There is a thin and folded layer of gray matter (GM) on the cerebral surface. Many studies have shown that abnormal changes in cortical thickness are highly associated with neurodegenerative diseases and psychiatric disorders, such as schizophrenia [1], Alzheimer's disease [2], and autism [3]. In our study, we focus on two issues, including evaluation of the cortical thickness and reconstruction of the cortical surface using segmented MR images. A layered distance method is proposed here and its applications to measuring cortical thicknesses and reconstructing cortical surfaces are presented.

II. Methods

The **layered distance map (LDM)** is acquired from the segmented MR images by a **layered distance function (LDF)**, i.e. $L(p)$, where p is an input voxel coordinate. Those voxels of GM and WM are first defined as two sets, G and W, respectively. The LDF is formulated as

$$L(N(q)) = L(q)+1,\ N(q)\in G, \tag{1}$$

where q represents labeled voxel coordinates and N is a neighborhood function in which the 6-connectivity is used, i.e., the 6-neighbors of q are denoted by $N(q)$. For initialization, the distance values of GM/WM interface are labeled as zeros, i.e., $L(q) = 0$, $q\in W$. Those unlabeled GM voxels which are 6-neighbors of WM voxels are secondly labeled as ones by (1). The LDF is calculated iteratively all over the segmented MRI images until all GM voxels are labeled. Finally, the distance values of all unlabeled voxels (e.g. CSF or other tissues), are also set to zeros.

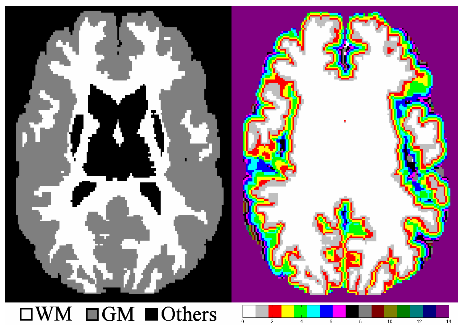


Figure 1: Segmented MR image and its layered distance map (LDM).

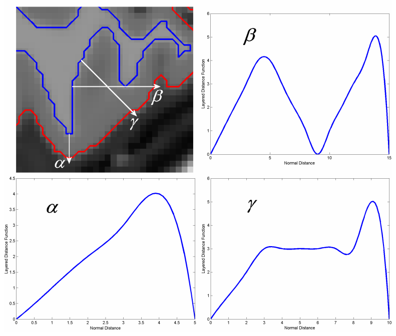


Figure 2: Examples of cortical layered distance (CLD) curves.

Figure 1 shows one slice of MR images and its LDM. According to LDM, the segmented MR images can be processed to construct different distance values in GM. Then the **cortical layered distance (CLD)** curves are formed with those distance values on LDM starting from every point on the GM/WM interface. Each point on the GM/WM interface can obtain a CLD curve along the normal direction toward outward of the surface. In our assumption, the values of CLD curves will increase and then decrease across the GM. Figure 2 shows some examples of CLD curves. The value of each CLD curve with detected decreasing gradient is computed to be the cortical thickness. By using this distance gradient algorithm, the cortical thickness can then be measured. On the other hand, the WM surface (i.e. GM/WM interface) is first reconstructed from the segmented MR images. This surface is then dilated and deformed to the LDM gradually by the **self-organizing map (SOM) model**. Finally, it will approach and form an obvious cortical surface. To implement the proposed algorithm, the segmented MR images are acquired from the IBSR [4] and BrainWeb [5].

III. Results

Application 1: Cortical Thickness Measurement

LDM → CLD curves → Distance Gradient Algorithm → Cortical Thickness

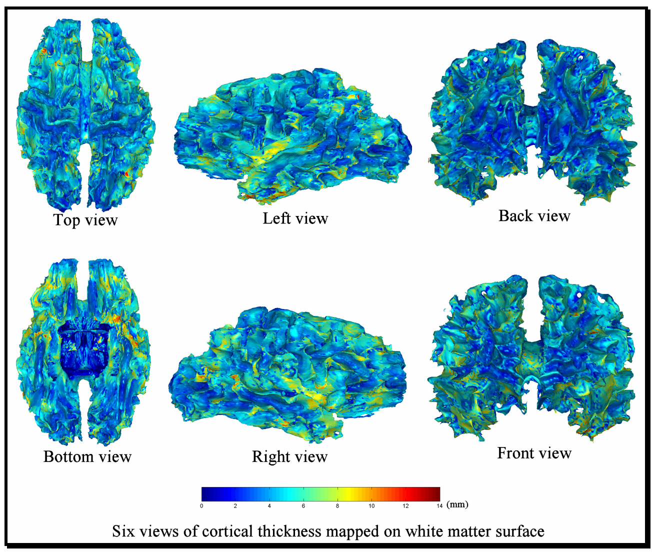
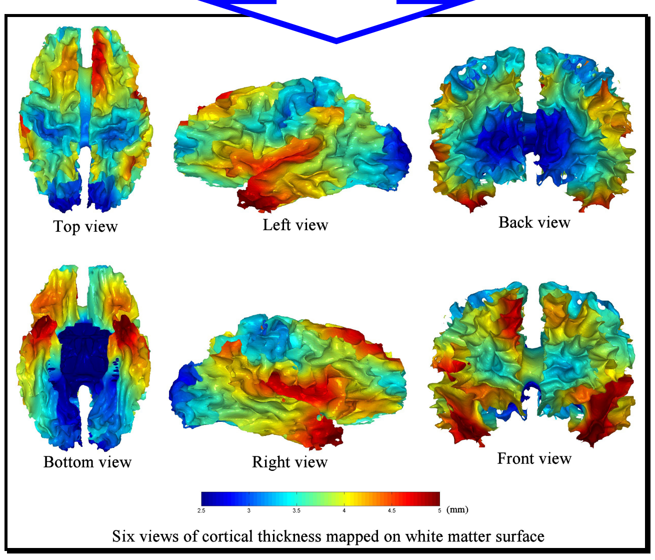


Figure 3: Six views of cortical thickness mapped on the white matter surface (measured by the proposed method). The mean thickness is 3.453 mm.

Smoothing & Colorbar Adjustment



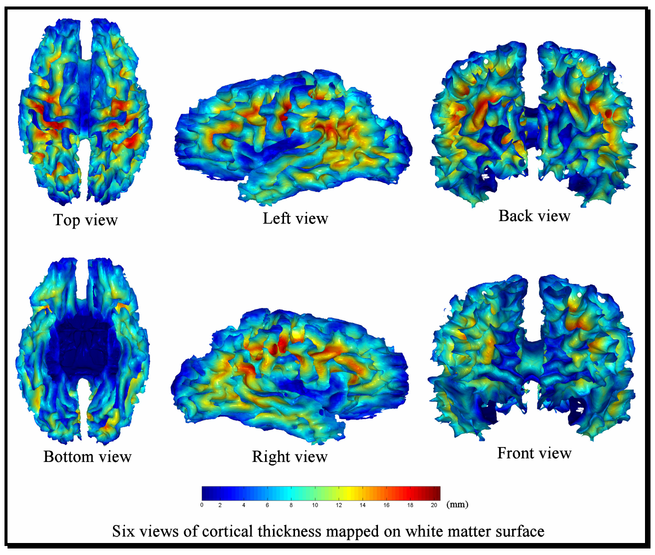
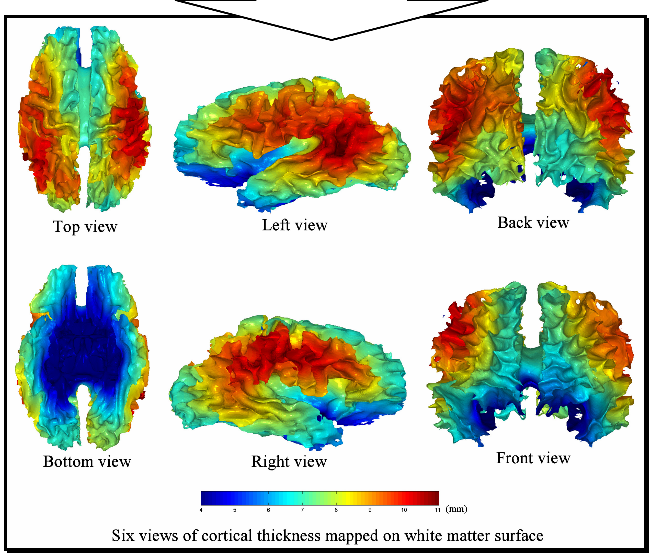


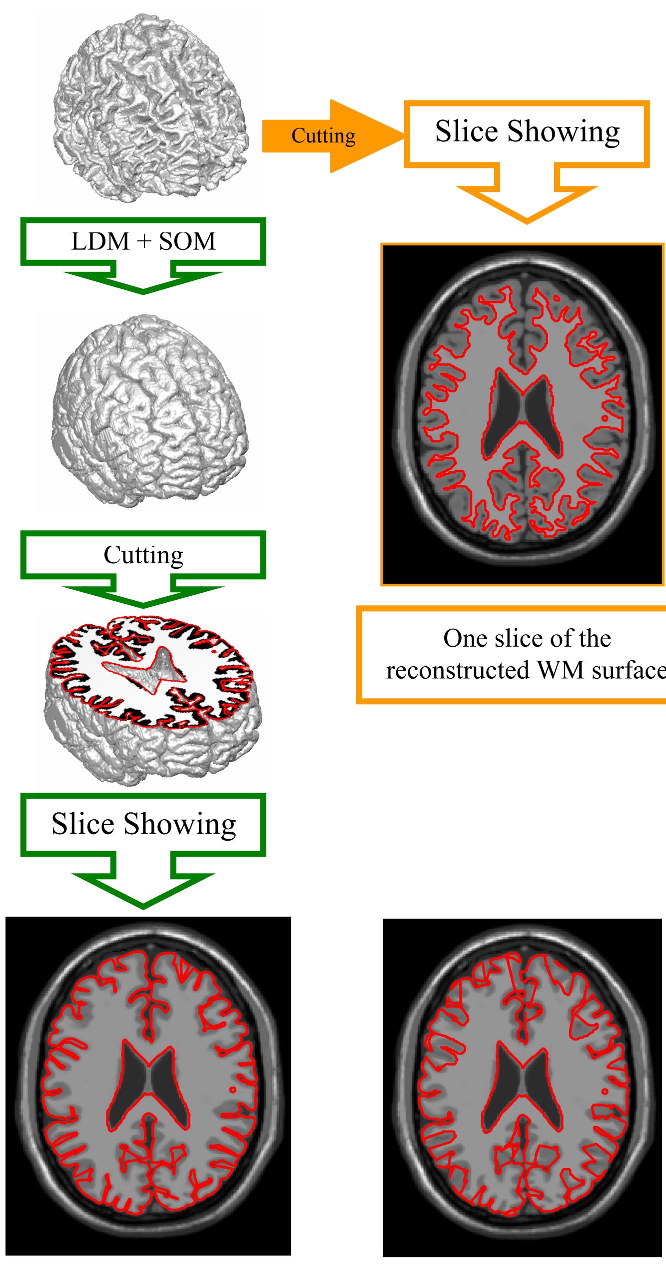
Figure 4: Six views of cortical thickness mapped on the white matter surface (measured by the shortest distance method, i.e. the shortest distance calculated from GM/WM to GM/CSF interfaces). The mean thickness is 6.952 mm.

Smoothing & Colorbar Adjustment



Application 2: Cortical Surface Reconstruction

LDM + SOM model → Cortical Surface



One slice of the reconstructed WM surface

Figure 5: One slice of the reconstructed cortical surface by the LDM+SOM model.

One slice of the reconstructed cortical surface by the SOM model (without LDM).

IV. Conclusions

A distance gradient algorithm is proposed to measure the cortical thickness and a SOM model is presented to reconstruct the cortical surface by using the LDM computed using segmented MR images. Based on these algorithms, the measured cortical thickness is more accurate than that of the shortest distance measurement, and the cortical surface reconstructed by the SOM model is clear inside the sulci. Our methods can be applied to measuring and analyzing the cortical thickness in association with some clinical diseases (e.g. neurodegenerative diseases or psychiatric disorders), and the 3D cortical surface can be used to support an estimation of neural dipoles of EEG signals and deformation measurement of the brain. Truly, the iterative SOM process takes a heavy computational load when the number of data and neural nodes is large. Fortunately, the parallel processing techniques are well developed and can be applied to the SOM model. This is the future work of our research.

References :

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[3] Chung, M.K. et al. 2005. Neuroimage 25(4): 1256 – 1265.
[4] Internet Brain Segmentation Repository (IBSR), http://www.cma.mgh.harvard.edu/ibsr/.
[5] BrainWeb, http://www.bic.mni.mcgill.ca/brainweb/.