

A Simple Method for the Automatic Measurement of Cortical Thickness

D. C. Bigler¹, Q. X. Yang², M. B. Smith²

¹Center for NMR Research, Department of Bioengineering, Penn State College of Medicine, Hershey, PA, United States, ²Center for NMR Research, Department of Radiology, Penn State College of Medicine, Hershey, PA, United States

Introduction

Measurements of cortical thickness are increasingly employed to study growth, aging, and disease progression in the human brain [1-3]. Most of the methods for this purpose are based on measurement of cortical surfaces rendered from segmented gray matter, which is calculation-intensive. A simple and reliable method for measuring cortical thickness is developed that produces a cortical thickness map directly from 2D or 3D segmented brain images.

Method

The measurement of cortical thickness is a 3-step process.

1) Identify GM voxels using any chosen MR brain image segmentation tool. **2)** The segmented 2D or 3D GM image is passed through a Euclidian distance filter [4]. The Euclidian distance filter replaces each non-zero voxel with the Euclidian distance from the non-zero voxel to the closest zero pixel as illustrated in Fig. 1. **3)** The Euclidian distance image is passed through a search algorithm that iteratively marks each non-zero voxel with a thickness.

Searching begins with the thickest value (the smallest image dimension) and ends with single voxel thicknesses. The algorithm scans the distance image for values that are half of a given thickness. When the desired distance value is located, its coordinates are used as the center of a circle in 2D and a sphere in 3D. The Euclidian distance value at that coordinate becomes the radius of the circle (sphere). For every zero voxel just outside the circle (sphere), the corresponding voxel on the opposite side of the sphere is checked to see if it is also a zero. If both voxels are zero, all the voxels in between are marked as having a thickness equal to twice the radius rounded to the nearest integer. Once a voxel is marked, it is ignored in subsequent search iterations. Fig. 1 shows a graphical representation of this last step.

Validation

The developed method was validated rigorously using a 2D and 3D test images containing a set of fundamental geometric shapes with known thicknesses relevant to brain gray matter as shown in Fig. 2. For demonstration purposes the algorithm was applied to a T₁-weighted 3D MDEFT (TE=3.14ms, TR=10.55ms, TI=680ms, SENSE factor=2, 20° flip angle) head image of a 29-year-old male subject on a Philips Intera 3.0 T system. The head image was smoothed using SUSAN [5] and brain extraction was performed using the brain extraction tool (BET) [6]. Segmentation was performed using the FAST [7] segmentation tool. The internal GM structures were manually removed from the segmented image prior to thickness processing.

Results and Discussion

The 2D and 3D test images are shown in Fig. 2. Examination of the two test images shows that the algorithm correctly identifies thickness in two and three dimensions, with the exception of the block touching the border in the 2D image where its thickness orientation is difficult to define. In the 3D case the algorithm measured the maximum thickness at the center of the ellipsoid as 16 voxels, which is the diameter in the z direction. The thickness tapers off on the periphery of the ellipsoid as expected. Fig. 3 shows a 3D rendering of the cortical thickness image overlaid on the original T₁-weighted brain image. Application of this method to an ongoing ALS study has shown visual differences in cortical thickness within the primary motor cortex.

References

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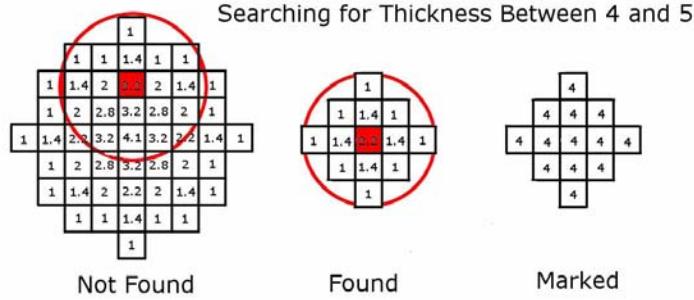


Figure 1: Graphical depiction of the search algorithm for a given thickness. The numbers in the boxes (voxels in 3D) represent the output of the Euclidian distance filter. The red circles depict the search area for a given Euclidian distance. A given thickness of 4 (voxel) is not found for the left object but is found in the middle object and subsequently marked.

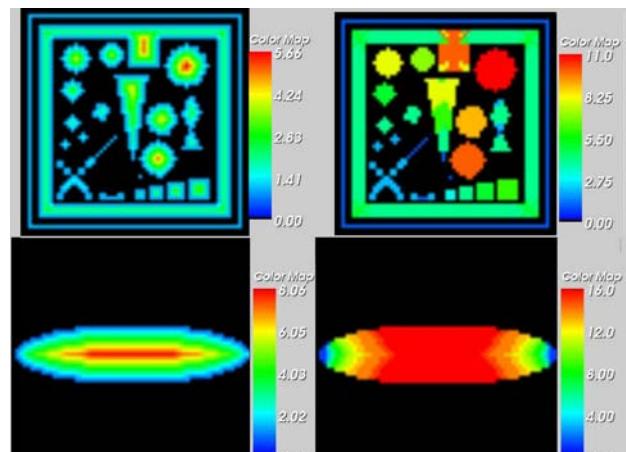


Figure 2: Euclidian distance (left) and thickness images (right) for 2D shapes (top row) and the center coronal slice of a 3D ellipsoid (bottom row) with pixel radiiuses of 32, 16, and 8 for the x, y, and z-axes respectively. Note that the maximum thickness measured in the 3D ellipsoid was 16, which is twice the z radius or the smallest radius specified for the ellipsoid. Notice also how the thickness tapers off on the sides.

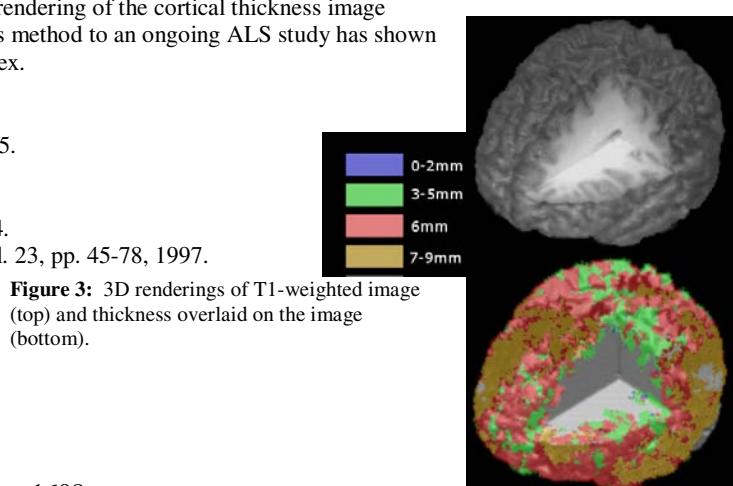


Figure 3: 3D renderings of T1-weighted image (top) and thickness overlaid on the image (bottom).