

Cortical Shape Analysis Using Spherical Wavelet Decomposition of Curvature

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Introduction

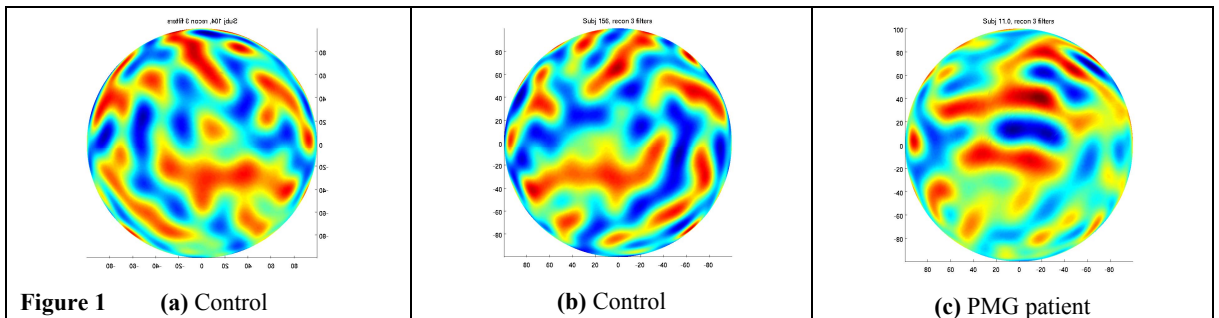
The pattern of complex folds on the human cortex is in an absolute sense unique: like fingerprints, every cortex is folded differently. Nonetheless, all human cortices share a common basic folding template. The magnitude of deviations from this template can indicate pathology. This paper presents a methodology based on analyzing the curvature across reconstructed cortices in an effort to distinguish normal and abnormal cortical shapes. Earlier work has considered global differences between normal and abnormal surfaces based on curvature distribution differences. In order to be globally significant, such variations must be either regionally large-scale or, if small-scale, must occur generally across the entire surface to be significant. In this paper, we refine this method and attempt to automatically determine regional differences where significant curvature-based topological variations are present. This approach requires good surface registration between all the subjects in the analysis, and a multi-scale method of describing discriminatory functions. We propose to represent this discriminatory function in different scales using either a wavelet decomposition or a spherical harmonic approach. By filtering out "high frequency" components we hope to simplify the similarity computation. In this manner, we hope to provide a novel technique that tags regional variations in surface curvature, and hence folding.

Materials and Results

We have collected standard structural MRI volumetric data (Siemens MPRAGE at 3T) on a cohort of ten neurologically normal (ages 2 to 11 yrs) and ten abnormal subjects (ages 3 to 10 yrs). The abnormal subjects are all suffering from polymicrogyria (PMG). Using FreeSurfer, we reconstructed cortical surface meshes. In order to perform meaningful comparisons, and to mitigate against the skewing effects of large topological outliers on abnormal subjects, we constructed a pair-wise registration across our entire subject space. Once registered, all surfaces were resampled to contain the same number of vertices.

Our similarity measure was driven by functions of curvature on the reconstructed meshes. These functions are developed from the k_1 (absolute maximal) and k_2 (absolute minimal) principle curvature values at each mesh point. Here we considered the Gaussian curvature $K=k_1k_2$. This function was wavelet filtered using spherical wavelets [Yeo 2008]. A single wavelet filter described the function at the most general scale,

increasing filters added more and more detail. For this paper, we considered functions of 3 wavelet filters as an appropriate trade-off between sufficient detail to capture topological features of



interest, but still coarse enough to discount the fine folding detail that does not meaningfully add to the question of normal vs abnormal folding patterns and which might in fact skew similarity comparisons. Results for two normal subjects and a PMG patient is shown in Figure 1.

Realizing that a simplistic vertex-point-by-point comparison of curvature value type does not provide a very sophisticated method of assessing similarity between surfaces, being too easily offset by minor differences in alignment and resample, we applied spherical harmonics as an effective encoding of the wavelet smoothed spherical functions. This expansion has been applied earlier to encoding of cortical folding [2]. In a subset of 5 controls and 7 patients, we performed hierarchical cluster analysis on the real part of the spherical harmonic coefficients. Figure 2 indicates a clustering of normal subjects, with just a single misclassified PMG patient.

Conclusion

Our next direct step is to perform a similarity analysis by using a Dijkstra-derived cost function calculated using curvature function values as graph edge cost, and then to map vertex costs onto FreeSurfer spherical maps. We hope that the combination of the clustering analysis and the Dijkstra cost approach will provide an effective method to discriminate between normal and PMG patient cortical surfaces.

References

[1] Yeo et al, IEEE Transactions on Image Processing 2008. [2] Chung et al, Statistica Sinica 2008.

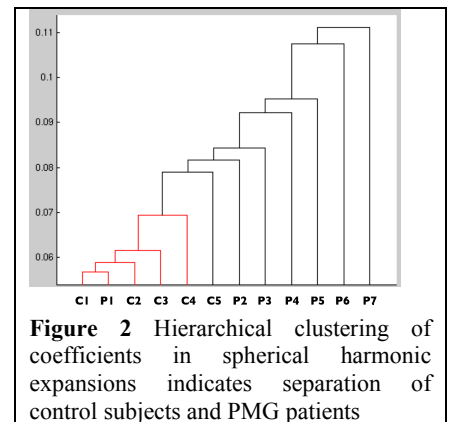


Figure 2 Hierarchical clustering of coefficients in spherical harmonic expansions indicates separation of control subjects and PMG patients