Analyzing the Developing Brain by Quantifying Curvature Measures

Rudolph Pienaar, Bruce Fischl, Nikos Makris, P Ellen Grant
Harvard Medical School, Boston, MA, United States
Massachusetts General Hospital, Boston, MA, United States

Introduction: Analyzing functions of curvature on brain surfaces can be a more sensitive marker for developmental disorders than most contemporary measurements that are often based on volume and surface-area measurements. We propose analyzing cortical manifolds using functions of curvature, calculated in an point-by-point manner on each vertex of a reconstructed surface. Such curvature functions are based on the principal curvatures that exist at each vertex mesh point. We also propose to adaptively filter the analysis at the scale of cortical folding, and so doing focus the analysis on areas of the cortical surface that are particularly significant from a developmental perspective. We would like to present results from this analysis over a cohort of developmentally normal neonate, pediatric, and adult surfaces. Furthermore, we have preliminary data on normal/abnormal pediatric polymicrogyria brains. Using curvature functions in this manner not only groups subjects correctly according to age, but also separates normal and abnormal polymicrogyria brains.

Methods: T1 weighted 3D SPGR images were collected from 13 normal and 5 abnormal subjects with resolutions of typically 1mm in-plane and 1.5mm thickness. Normals comprised 7 neonates from 34.0 weeks through 40.3 weeks corrected Gestational Age (cGA); 3 children of 2, 3, and 7 years (104, 156, and 365 weeks); and 3 adults of 33, 34 and 40 years (1734, 1770 and 2054 weeks). Polymicrogyria abnormals comprised 5 children of ages 4, 4, 5, 5 and 11 years. Once collected, gray/white surfaces were reconstructed using FreeSurfer and analyzed for the distribution of maximum curvature k_1, and minimum curvature k_2. Basic functions of these curvatures include the mean curvature, $H=\frac{1}{2}(k_1 + k_2)$ and the Gaussian curvature, $K= k_1 k_2$. Additional functions of curvature including a sharpness of curvature $S = (k_1 - k_2)^2$, and its integral $\int S dA$ (the Willmore Bending Energy).

Examples of projections of k_1, k_2 , and S on the surface of an inflated 38 week CGA neonate are are given in Figures 1, 2, and 3.

Figure 1 - Projection of k_1 on reconstructed and inflated 38 week subject

Figure 2 - Projection of k_2 on reconstructed and inflated 38 week subject

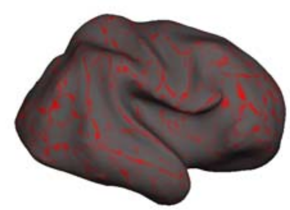
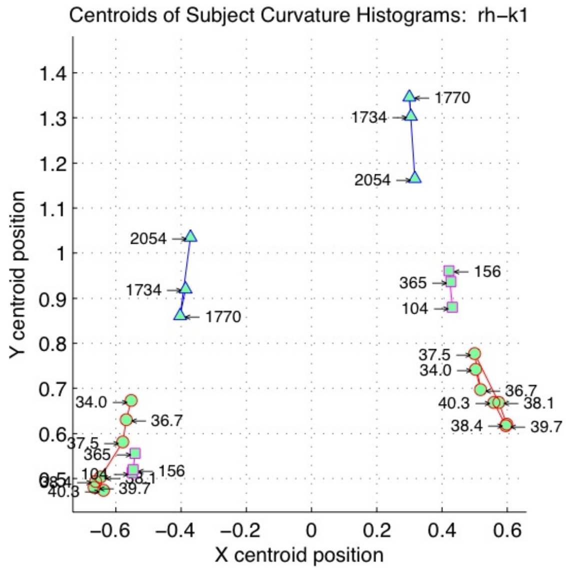


Figure 3 - Projection of S on reconstructed and inflated 38 week subject

For a given subject, curvature values and functions were determined across the gray/white surface. A histogram function summarized the distribution of curvature values across the surface. The positive and negative curvature lobes of this histogram were considered separately, and the geometric centroid of each lobe was determined. These centroids were plotted on coordinate axes and their clustering properties examined. The curvature analyses were also filtered through a novel adaptive filter based on the intrinsic Gaussian curvature function. In order to focus the analysis specifically on the scale of gyri and sulci, this filter was tuned to specific radii of curvature ranging from $3mm^{-1}$ to $7mm^{-1}$. For each radius, only surface regions that had correspondingly higher Gaussian curvature were analyzed.

Results: The histogram/centroid analysis showed very good discriminatory clustering. For the normals, the method cleanly clustered the different age groups, particularly for the S and k_1 curvature functions (Figures 3 and 4 -- neonates as circles, children as squares, adults as triangles).



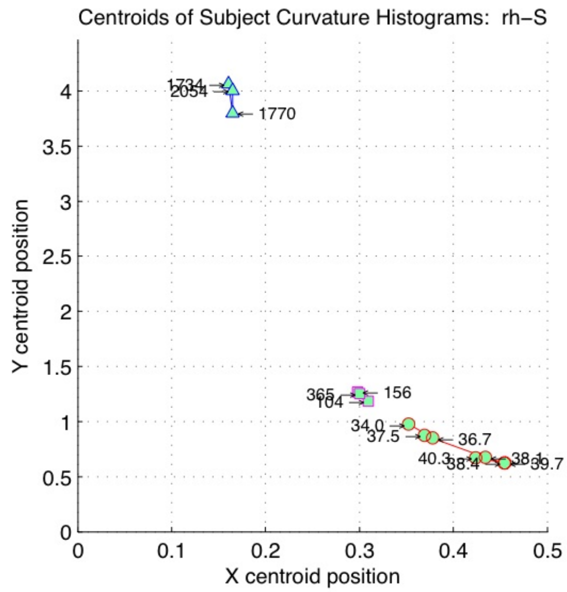


Figure 3 - Histogram/Centroid analysis of k_1 curvatures across cohort of normal subjects from neonate to adult.

Figure 4 - Histogram/Centroid analysis of S curvatures across cohort of normal subjects from neonate to adult.

In a similar vein, for the abnormals, the k_1 , k_2 , and S curvature clustering also provided excellent classification between normal and abnormal populations (see for example Figure 5 -- abnormals as circles, normals as squares for the k_2 curvature).

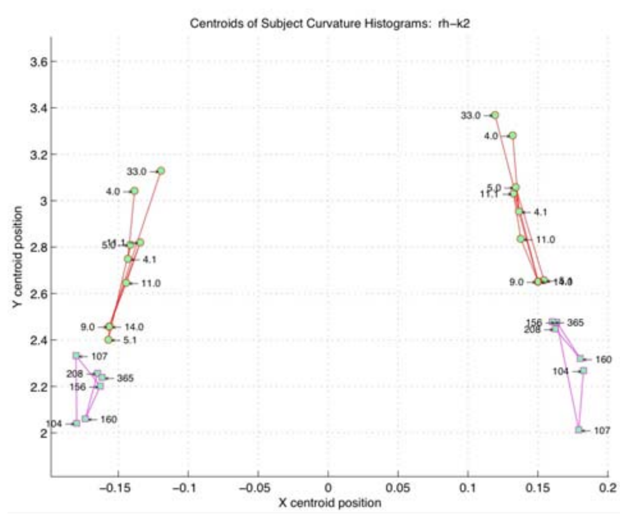


Figure 5 - Histogram/Centroid analysis of k_2 curvatures between normal and polymicrogyria subjects.

A frequency decomposition confirmed that in general the k_1 curvature has a dominant component commensurate with the major folding pattern gyri and sulci. The k_2 curvature showed very high oscillations, and seemed to track low amplitude, high frequency oscillations running along the major axis of gyri and sulci.

Conclusions: We present a surface developmental approach that analyzes properties of curvature functions on reconstructed surfaces and is able to classify brain surfaces in an age-based manner and also distinguish between normal and malformed subjects.