Journal of Visualization,

Short Paper

NURBS-Based Visualization of Age-Related Diversity in Cortical Morphology

Meegama, R.G.N.*[1] and Rajapakse, J.C.*[2]

*1. Centre for Computer Studies, Sabaragamuwa University, Belihuloya, Sri Lanka, 70140.
E-mail: rgn@sab.ac.lk
*2. School of Computer Engineering, Nanyang Technological University, Nanyang Avenue, Singapore.
Email: asjagath@ntu.edu.sg

Introduction

In neurology, it is known that different motor and cognitive functions in humans are mapped on specific cortical surface patterns of the brain. The variability in these surface patterns between individuals is caused by local differences in the rate of angular deformations of cerebral tissues during brain development. It has been reported that age effects of the human brain result in significant changes in the cortical volume (Courchesne et al., 2000). Moreover, the locations of individual convolutions on the brain surface depend on local changes in cortical structure,
with sulci occurring in relation to boundaries between cortical architectonic fields. Additionally, the importance of visualizing medical images, especially in 3D for clinical applications involving the brain, is immense (Linney and Alusi, 1998). Therefore, a method to analyze and visualize age-related variability of surface patterns is useful in neuro-imaging studies to detect various functional disorders and behavioral changes between children and adults (Kolb, 1993). The investigation in this paper presents a new approach based on statistical analysis of curvature changes in deformation vectors of a NURBS surface to compute and visualize the variability associated with surface patterns of the human brain.

Methods and Material

Let $\mathbf{p}_{i,j}^{t}$, $i = 0,1,\ldots,n-1$, $j = 0,1,\ldots,m-1$ be the control points having real positive weights $w_{i,j}^{t}$, of a NURBS surface $\mathbf{S}$, at time t given by

$$\mathbf{S}(u,v,t) = \sum_{i=0}^{n-1}\sum_{j=0}^{m-1} R_{i,j}(u,v,t)\mathbf{p}_{i,j}^{t}$$

where

$$R_{i,j}(u,v,t) = \frac{w_{i,j}^{t} N_{i,p}(u) N_{j,q}(v)}{\sum_{c=0}^{n-1}\sum_{d=0}^{m-1} w_{c,d}^{t} N_{c,p}(u) N_{d,q}(v)}$$

are the rational basis functions in which $N_{l,k}$ gives the l^{th} B-Spline basis function of degree $k \in Z^{+}$ (Piegl and Tiller, 1995).

The proposed technique finds the significant variability of sulci and gyri patterns on the cerebral lobes by deforming an average NURBS surface, corresponding to the group of interest, onto each subject. If $\bar{\mathbf{S}}(u,v,t)$ denotes a point on the average surface at time t, the deformation vector $\mathbf{d}$ of this point is given by

$$\mathbf{d}(u,v) = \bar{\mathbf{S}}(u,v,t+1) - \mathbf{S}(u,v,t)$$

Using the first and second fundamental forms, the mean curvature κ can be expressed as

$$\kappa(u,v,t) = \frac{eG - 2fF + gE}{2(EG - F^2)}$$

where $E = \left|\mathbf{S}_u^2\right|$, $F = \mathbf{S}_u \cdot \mathbf{S}_v$, $G = \left|\mathbf{S}_v^2\right|$, $e = -\mathbf{S}_u \cdot \mathbf{n}_u$, $f = 0.5(\mathbf{S}_u \cdot \mathbf{n}_v + \mathbf{S}_v \cdot \mathbf{n}_u)$ and $g = \mathbf{S}_v \cdot \mathbf{n}_v$, $\mathbf{n}$ is the unit normal vector at $\mathbf{S}(u,v,t)$ and $\mathbf{n}_u = \frac{\partial \mathbf{n}}{\partial u}$. The partial derivatives of $\mathbf{S}$ are given by $\mathbf{S}_u = \frac{\partial \mathbf{S}}{\partial u}$ and $\mathbf{S}_v = \frac{\partial \mathbf{S}}{\partial v}$ (Gray, 1993). Hence, when the point $\mathbf{S}(u,v,t)$ deforms to $\mathbf{S}(u,v,t+1)$, the change in mean curvature $\kappa'(u,v,t)$ is given by

$$\kappa'(u,v,t) = 0.5(\kappa(u,v,t+1) - \kappa(u,v,t))$$

Now, the change in mean curvature at a point $\mathbf{S}(u,v,t)$ is taken as a measure of variability on the surface segment $\mathbf{S}(u,v,t)$, $u \in \lfloor u_i, u_{i+p+1})$, $v \in \lfloor v_j, v_{j+q+1})$. To relate and compare surface patterns across different subjects, it is imperative to establish a mapping that specifies a unique correspondence between each location in one brain and the corresponding location in another (Fischl et al., 1999). The initial (before deformation) template NURBS surface, $\overline{\mathbf{S}}$, is obtained by averaging the brain surface within a particular group as

$$\overline{\mathbf{S}}(u,v,t) = \frac{1}{l}\sum_{i=1}^{l} \mathbf{S}_i(u,v,t)$$

where $\mathbf{S}_i$ denotes the NURBS surface of the brain corresponding to the subject i, i=1,2,…,l. Now, under the null hypothesis that no curvature change on the surface point $\overline{\mathbf{S}}(u,v,t)$, compute and upper control limit (UCL) for the curvature changes as

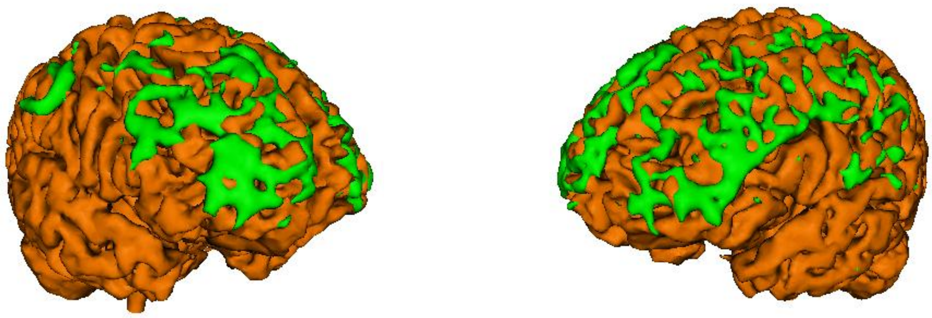
$$UCL = \frac{1}{l} s\, t_{\alpha/2,l-1}$$

where $t_{\alpha/2,l-1}$ gives the upper 100α percentile of the t distribution with l-1 degrees of freedom and s is a T-statistic.

Results and Discussion

Magnetic resonance scans of [illegible]5 individuals obtained from National Institutes of Health (NIH), Bethesda, USA, were used in the experiments. These axial T1-weighted datasets were acquired on a GE 1.5 T Signa scanner with TR=24 ms, TE=5 ms, flip angle = 45°, slice thickness = 1 mm, 192x256 pixels per slice and 124 slices per 3D image. The dataset was processed using statistical computations on curvature changes of the deformations to obtain significant variations in brain surface patterns between the subjects. Figure 1 displays the local variations of the relevant segments on both left (Fig. 1(a)) and right (Fig. 1(b)) sides of the brain surface in 3D. The percentage variability in each subject due to such significant curvature changes, compared to the total surface area, is shown in Figure 2.

The new NURBS–based method introduced in this paper is an approach that extends the deformation-based morphometry (Ashburner et al., 1998) and tensor-based morphometry (Chung et al., 2002) with a NURBS deformable surface to detect significant age-related changes in brain surface patterns in normal males. Statistical analysis on significant curvature changes implies variability on surface patterns related to age. The results also indicate that the spread of variation on the brain surface decreases with age. Because specific surface patterns map distinct cortical activations in the brain, the present research will potentially serve as a clinical tool for functional and behavioral analysis of the evolutionary human brain.



(a) right side of the brain (b) left side of the brain

Figure 1. Variability in surface patterns among normal male subject between 4-18 years (surface segments in green indicate locations where significant variability is detected).

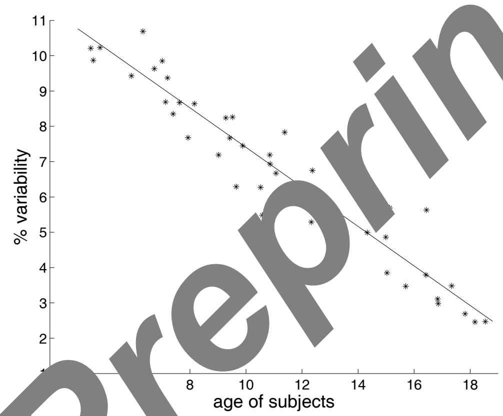


Fig. 2. The % a[illegible] of surface variability in the subjects with corresponding age.

References

Ashburner, J., Hutton, C., Frackowiak, R., Johnsrude, I., Price, C. and Friston, K., Identifying global anatomical differences: Deformation-based morphometry, Human Brain Mapping, 6(1998), 348-357.

Chung, M.K., Worsley, K.J., Paus, T., Robbins, S., Taylor, J., Giedd, J.N., Rapoport, J.L. and Evans, A.C., Tensor-based Morphometry, Technical Report 1049, Department of Statistics, University of Wisconsin, U.S., January 2002.

Courchesner, E., Chisum, H.J., Townsend, J., Cowles, A., Covington, J., Egaas, B., Harwood, M., Hinds, S. and Press, G.A., Normal Brain Development and Aging, Quantitative Analysis of in vivo MR Imaging in Healthy Volunteers, Radiology, 216(2000), 672-682.

Fischl, B., Sereno, M.I., Tootell, R.B.H. and Dale, A.M., High Resolution Inter-Subject Averaging and a Coordinate System for the Cortical Surface, Human Brain Mapping, 8(1999), 272-284.

Gray, A., Modern Differential Geometry of Curves and Surfaces, (1993), CRC Press.

Kolb, B., Brain Development, Plasticity and Behavior, Brain Development and Cognition: A Reader, (1993), Blackwell, Oxford.

Linney, A.D. and Alusi, G.H., Clinical Applications in Computer Aided Visualization, Journal of Visualization, 1(1998), 95-110.

Piegl, L. and Tiller, W., The NURBS Book, (1995), Springer-Verlag.