Four-Step Approach for Flattenning Brain Surface onto Sphere and Plane

M. Kwon[1], H. Park[1]

[1]Electrical Engineering and Computer Science, Korea Advanced Institute of Science and Technology, Daejeon, Korea, Republic of

Abstract:

Flattening of the brain surface onto sphere and plane is widely used to view the buried sulci of cerebral cortex. Conventional parametric deformable models usually result in self-intersection and the resultant triangles may overlap at thin and deep concave region because vertices are deformed by combination of the external forces. Although some algorithms solve the overlap problem, they require heavy computation and do not guarantee no-overlap between triangles. This paper proposes a method that flattens the brain surface onto sphere and plane without overlap between triangles, with small computational time, and with minimized metric distortion. The proposed method organized by four steps each of which takes charge of specific purpose. In each step, deformation is performed just by one force and the effect of force is maximized. Flattening to sphere and plane need three and four steps, respectively. Vertices are deformed in 2D (θ,ϕ) Spherical coordinates for flattening to sphere in order for vertices to exist exactly on sphere and 2D (x,y) Cartesian coordinates for flattening to plane.

Introduction:

Cerebral cortex grows into highly folded and the amount of 60-70% of the sulci is buried[1]. Flattening the cerebral cortex onto sphere and plane are useful methods to visualize the deep sulci and function effectively. Conformal mapping is used to preserve the angles between vertices, however, it has large metric distortion[2]. Parametric deformable models are used to minimize metric distortion by iteration processes[1][3]. Fischl tried to reduce metric distortion after vertices of a surface were mapped onto sphere and plane[1]. However, in the thin and deep concave region such as sulci, the vertex of a region can be intersected with those of other regions and triangles on sphere can overlap.

Material and methods:

Figure 1 shows overall block diagram of the proposed four-step flattening method. Flattening to sphere needs step1, step3, and step4. Flattening to plane needs step1, step2, step3, and step4. In step1, after vertices are projected onto sphere just once, vertices are smoothed iteratively until there is no overlap between triangles. Step2 plays the same with step1 except that the projected vertices onto sphere after step1 are mapped on plane. In step3, the projected vertices from step1 and step2 are smoothed and normalized in a way that maximum and minimum θ of all vertices are 0 and π, respectively. Then, distortion is minimized globally. In step4, the deformed vertices from step3 are deformed to minimize distortion locally. Step3 and step4 end if difference of distortion between t^{th} and $(t-1)^{th}$ iteration is less than ε, which is 0.01% here. Spherical and Cartesian coordinates of vertices can be transformed by trigonometric function. Except initial projection to sphere in step1, deformation is performed in 2D Spherical coordinates for flattening to sphere. This makes vertices exist on sphere, which do not if deformation is performed in 3D Cartesian coordinates. All steps need a fast method to examine overlap between triangles. Computational cost is reduced from O((the number of triangles)^2) to O((the number of triangles)) by examining orientation of triangles instead of brute-force method that checks all pairs of two triangles.

Results and Discussions:

Experimental brain MR images were obtained as a sample data of FreeSurfer package[4].The experiment was performed at 3GHz Pentium IV with 1GB memory using Visual C++ under Windows 2000 for the proposed flattening method and Linux for FreeSurfer. Figure 2 shows the native, the inflated, and the flattened surfaces of cortex for the left brain, which are acquired from FreeSurfer. Flattened surfaces by the proposed method are also shown. Distortion and the number of triangles that may overlap are shown in Table 1. Distortion of the flattened surface to sphere is lower in the proposed method than FreeSurfer. Although distortion of the flattened surface to plane is larger in the proposed method than FreeSurfer, distortion can be minimized more with smaller ε. Computational time was reduced largely and overlap between triangles does not happen in the proposed method.

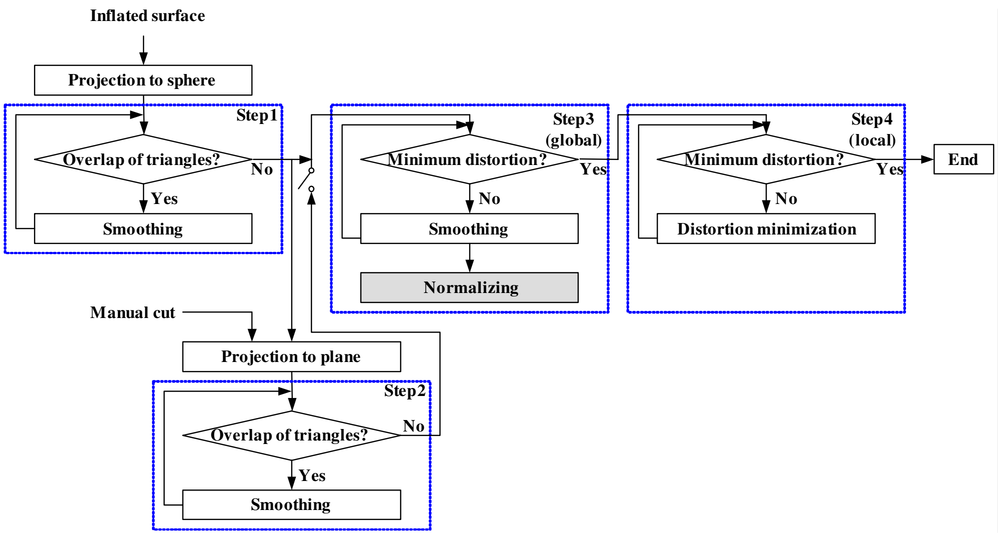

Figure 1. The proposed algorithm

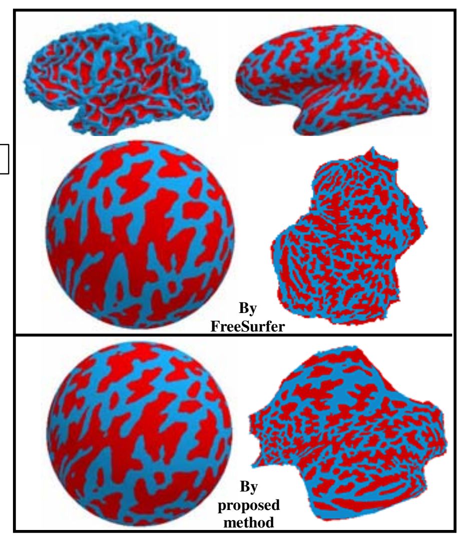

Figure 2. The experimental results

		Computational time (s)	# of reversed face	Distortion (%)	
				Mean	Max
FreeSurfer	Sphere	3161	531	29.26	432.5
	Plane	6722	13	20.51	241.2
The proposed	Sphere	186.3	0	23.03	392.5
	Plane	91.14	0	31.44	617.2

Table 1. Quantitative information

Conclusions:

The proposed four-step approach provides the flattened surfaces to sphere and plane without overlap between triangles, with small computational amount, and with minimized distortion.

References:

[1] B. Fischl et al., NeuroImage 9: 195-207, 1999 [2] S. Angenent et al., IEEE Trans. Medical Imaging 18(8): 700-711, 1999 [3] D. MacDonald, NeuroImage 12: 340-356, 2000 [4] http://www.nmr.mgh.harvard.edu/freesurfer/