Optimization of Brain Conformal Mapping with Landmarks

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Objective: One way to analyze and compare brain data from multiple subjects is to map them conformally into a canonical space, such as a sphere. Ideally, the map should retain information on the surface geometry as far as possible. The aim of the study was to adjust the conformal parameterizations of several cortical surfaces to allow landmark features to lie in consistent parametric locations, while optimally preserving the conformality of the parameterization.

Methods: Our method is based on a new energy functional. It optimizes the conformal parameterization of cortical surfaces by using manually traced landmarks to align one surafce with another (see Figure 1). This is done by minimizing the compound energy functional:

$$E_{new} = E_{harmonic} + \lambda E_{landmark}$$

where $E_{harmonic}$ is the harmonic energy of the parameterization and $E_{landmark}$ is the landmark mismatch energy. Mathematically,

$$E_{new}(f) = \int \| \nabla f \|^2 + \lambda \int \delta_E \| f - g \|^2$$

where E is the set of discrete landmarks and g is the conformal parametrization of the cortical surface.

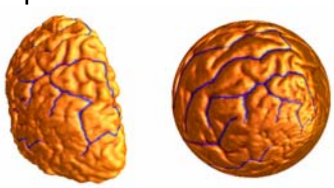

Figure 1. Manually labeled landmarks on the brain surface. The original surface is on the left. Its conformal mapping result to a sphere is on the right.

Results: We tested our algorithm on a set of left hemisphere cortical surfaces generated from brain MRI scans of 40 healthy adult subjects, aged 27.5+/-7.4SD years (16 males, 24 females), scanned at 1.5 T (on a GE Signa scanner). Experimental results showed that the landmark mismatch energy can be significant reduced while effectively preserving conformality.

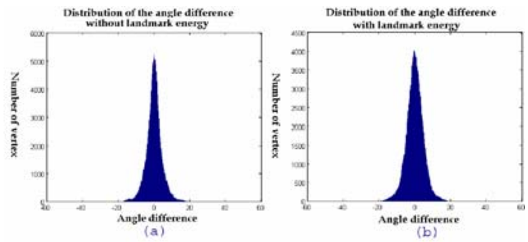

Figure 2. Histogram (a) shows statistics of the angle difference using the conformal mapping. Histogram (b) shows the statistic of the angle difference using our algorithm (with λ=3). The concentration of the histogram around zero shows that angles are well preserved (i.e., the mapping is close to conformal) even when a large set of landmark constraints are enforced.

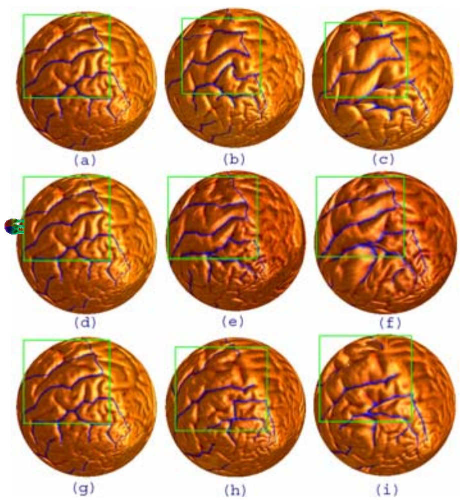

Figure 3. In (a), the cortical surface C_1 (of a reference subject) is mapped conformally($\lambda = 0$) to the sphere. In (b), another cortical surface C_2 is mapped conformally to the sphere. The sulcal landmarks appear very different from those in (a) (see landmarks in the green square). In (c), the cortical surface C_2 is mapped to the sphere using our algorithm (with λ=3). The landmarks now closely resemble those in (a) (see landmarks in the green square). (d) and (g) show the same cortical surface (the reference subject) as in (a). In (e) and (h), two other cortical surfaces are mapped to the spheres. The landmarks again appear very differently. In (f) and (i), the cortical landmarks are aligned on the sphere using our algorithm. The landmarks now closely resemble those of the reference subject.

	$\lambda = 3$	$\lambda = 6$	$\lambda = 10$
$E_{harmonic}$ of the initial (conformal) parameterization:	100.6	100.6	100.6
$\lambda E_{landmark}$ of the initial (conformal) parameterization:	81.2	162.4	270.7
Initial compound energy $(E_{harmonic} + \lambda E_{landmark})$:	181.8	263.0	371.3
Final $E_{harmonic}$	109.1 ($\nearrow$ 8.45%)	111.9 ($\nearrow$ 11.2%)	123.0 ($\nearrow$ 22.2%)
Final $\lambda E_{landmark}$	11.2 ($\searrow$ 86.2%)	13.7 ($\searrow$ 91.6%)	15.6($\searrow$ 95.8%)
Final compound energy $(E_{harmonic} + \lambda E_{landmark})$	120.3 ($\searrow$ 33.8%)	125.6($\searrow$ 52.2%)	138.6 ($\searrow$ 62.7%)

Table 1: Numerical data from our experiment. The landmark mismatch energy is significantly reduced while the harmonic energy is only slightly increased. The table also illustrates how the results differ with different values of λ .The landmark mismatch error can be reduced by increasing λ , but conformality will increasingly be lost.

Conclusions: We developed a new method to optimize the conformal parametrization of cortical surfaces. Our algorithm can compute a map from the cortical surface of the brain to a sphere, which can effectively retain the original geometry while minimizing the landmark mismatch error across different subjects. The development of conformal mapping that can align surface landmarks may be beneficial in computational anatomy and multi-subject integration of functional imaging data.

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