Improved cortical boundary registration for locally distorted fMRI

Tim van Mourik[1], Peter J Koopmans[1], and David G Norris[1]

[1]*Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands*

Target Audience: Brain researchers that are interested in high resolution fMRI, for example laminar fMRI.

Purpose: Functional MRI scans are often locally distorted with respect to the structural scan, specifically in the phase-encoding direction in EPI images. We propose a spatially specific registration procedure, using the brain surfaces generated by FreeSurfer[1]. The proposed method uses the theory behind Boundary Based Registration[2] (BBR). This is particularly appropriate for high-resolution EPI and makes it possible to separately correct each acquired volume without the need for a field map, which may be rendered inaccurate by subject motion. Exceedingly high spatial accuracy is a necessity for example when examining the cortical layers: sampling a millimetre off from the correct position means sampling in a different layer.

Methods: BBR displaces the triangle mesh generated by FreeSurfer in order to maximise the contrast at the boundary of the white matter and grey matter and hence finds the best transformation matrix for the mesh to match the volume. Similarly, we find an optimal transformation by maximising the contrast, using a gradient descent method in MATLAB. After an initial registration, our method splits the mesh into two parts separated by a plane of arbitrary orientation, such that the number of vertices is equal for both parts. The algorithm finds the optimal transformation for both selections and applies them. The meshes are again cut in half using a plane orthogonal to the first; the optimal transformation is computed and applied. This procedure is iterated until a compartment contains fewer vertices than a given threshold number: below this number there is a higher chance that the transformation will be trapped in a local minimum away from the actual boundary. This threshold is typically around several thousands of vertices. For a whole-brain mesh, this comes down to roughly seven iterations. The iteration of rigid body transformations on small parts of the mesh creates a non-linear registration. This significantly improves the whole-brain accuracy of the

mesh. It may create some artefacts where the mesh was cut. In order to reduce these edge artefacts and increase robustness, the method can be run several times, but with different splits in different spatial dimensions. Taking the median of the displacement of several runs yields a very robust result.

Results: The method was tested on two different data sets: The first consisted of 30 subjects' EPI scans from a 3T scanner (0.8^3mm^3, TR/TE/α=3792ms/30ms/18°, with a pause of one TR after every third volume. Subtracting the third scan from the first creates a T1 contrast and is shown in Fig. 1). The image shows a cross-section of the result of the registration for a typical subject: the original surface is a mesh generated by FreeSurfer and the structural scan was registered with the functional scans using SPM[3]. The bottom half of the picture shows the registered surface. This follows the actual grey matter boundary much better than the original. Fig. 2 shows one subject from a second dataset that consisted of 12 subjects, 3D EPI at 7T (0.9^3mm^3, TR/TE/α=2768ms/20ms/14°**).** For all 42 subjects, the grey and white matter surface registration was clearly improved, demonstrating the robustness and accuracy of the method. Moreover, the recursive algorithm as well as the gradient descent method are both computationally efficient.

Figure 1: The top picture shows the original surface with a zoomed version of a locally distorted EPI image at 3T. The bottom picture shows the boundary that is moved to the correct location by means of our method.

Discussion: Studies in which high spatial accuracy is required would benefit greatly from this new method. Instead of one registration process there are many, increasing in specificity at each stage. The difference between the original position and the newly found position can be transformed into a field map. As the procedure makes use of the boundaries of the grey matter, this field map will only be defined around the grey matter. The method requires sufficient contrast between white and grey matter, since the contrast at the white matter boundary is maximised. One of the reasons for the development of this technique is the desire to analyse fMRI at the laminar level. Our registration technique opens up possibilities for routine whole brain laminar fMRI.

Conclusion: We propose a new registration method that is an iterative multiscale approach to boundary based registration for computationally efficient, robust non-linear coregistration of high resolution functional to structural data.

References:

[1] Dale AM, Fischl B, Sereno MI. Cortical surface-based analysis. I. Segmentation and surface reconstruction. NeuroImage 1999;9(2):179-194

[2] Greve D, Fischl B. Accurate and robust brain image alignment using boundary-based registration. NeuroImage 2009;48 63-72

[3] Collignon A, Maes F, Delaere D, Vandermeulen D, Suetens P, Marchal G. Automated multi-modality image registration based on information theory. Proceedings of IPMI 1995
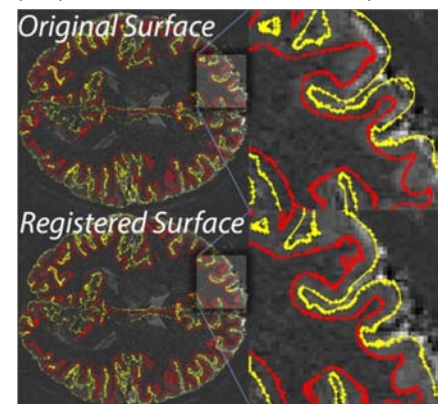
Figure 2: The top picture shows the original surface with a zoomed version of a locally distorted EPI image at 7T. The bottom picture shows the boundary that is moved to the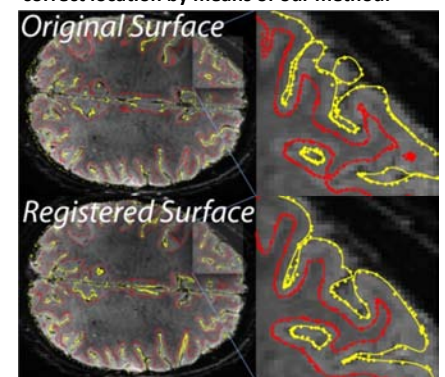 correct location by means of our method.