Robust fusion of Jacobian maps for Deformation-Based Morphometry

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Introduction

In population studies with Magnetic Resonance Imaging (MRI), Deformation-Based Morphometry (DBM) [Ashburner, 1998] has received more and more attention as a tool to investigate and identify anatomical differences between groups in cross-sectional studies or anatomical changes over time in longitudinal studies. In DBM methods, statistical analysis of the parameters required to normalize all subjects into a common space enables the localization of even subtle brain shape changes. However, DBM is highly dependant on the non-linear registration accuracy used for normalization. Registration errors due to anatomical singularities such as non-homologous gyri, the presence of lesions or image artifacts may result in outliers in the analysis. While smoothing may reduce the resulting adverse effects of these errors, it may also lead to over-smoothing of the results and reduce localization power. Therefore, we propose a method to improve the robustness of the DBM method by using a robust patch-based aggregation of Jacobian maps in order to preserve fine local brain changes. The method is evaluated using MRI data from 20 patients with multiple sclerosis.

Method

In this study, 20 T1W images with $1mm^3$ resolution of multiple sclerosis patients, went through the same processing stages: intensity non-uniformity correction [Sled, 1998], intensity normalization [Nuyl, 1999], linear-registration [Collins, 1994]. The log-transformed Jacobian was computed from the non-linear registration to the ICBM-152 template [Avants, 2004].

In the context of medical imaging, acquisition artifacts, the presence of pathology as well as inaccuracies in image processing may result in non-normal distribution of errors in estimated parameters. Robust estimators such as median should be used instead of the mean in order to deals with these outliers. In this study, we adapt a robust estimator based on patches in a fashion similar to that recently proposed for MR image denoising and template creation [Coupé, 2008, 2010]. Robust patch-based estimation utilizes similarity of a multi-voxel patch instead of single voxel intensity to detect outliers. Therefore, during the estimation of the population Jacobian, the patch-based robust estimation takes into account local image structure and preserves the fine image registration.

We initialize estimation of the population Jacobian $J^0(x)$ by computing the median at each voxel. Then iteratively, until convergence is reached, we estimate the 3D patch distance (L2-norm) between each subject's Jacobian $J_k(x)$ and the previous estimation of the population Jacobian $J^{t-1}(x)$; this distance is used to calculate a weighted average which is used as new estimate of the population Jacobian. A normalization factor $h(x)$ is calculated at each iteration as the median of patch distances. The method is mathematically described in Fig. 1.

$$\widehat{J^{t}(x)}=\sum_{k=1}^{n}\omega(\widehat{J^{t-1}(x)}, J_k(x)).J_k(x)$$

where $\widehat{J^{t}(x)}$ is the estimated Jacobian of the population at the iteration t for the voxel x while J_k is the Jacobian of the patient k. And the weight ω evaluate the intensity similarity of the patches $N(J^{t-1}(x))$ and $N(J_k(x))$ such as:

$$\omega(\widehat{J^{t-1}(x)}, J_k(x))=\frac{1}{C(x)}\exp-\frac{\|N(\widehat{J^{t-1}(x)})-N(J_k(x))\|_2^2}{h(x)}$$ where $C(x)$ ensures that $\sum_{k=1}^{n}\omega=1$.

Figure 1: Mathematical description of the robust patch-based method

Results

A robust DBM analysis is expected to produce a better defined representation of the morphological differences with the template – atrophy due to MS in the case the 20 patients analyzed here, with reduced variance due to elimination of outliers. We compare performance of the classical mean, individual Gaussian smoothing average and the robust technique with different patch sizes (1, 2, 3 and 4mm). We measure the mean and the standard deviation of the Jacobian aggregation for each method. Results are shown in Fig. 2 and summarized in Fig. 3. Compared to the two standard approaches (classical mean and Gaussian smoothing), our proposed approach showw a more refined identification of local changes (i.e. : ventricles, sulci...) Theses results are confirmed with the overall smaller standard deviation for the smaller patches (1mm).

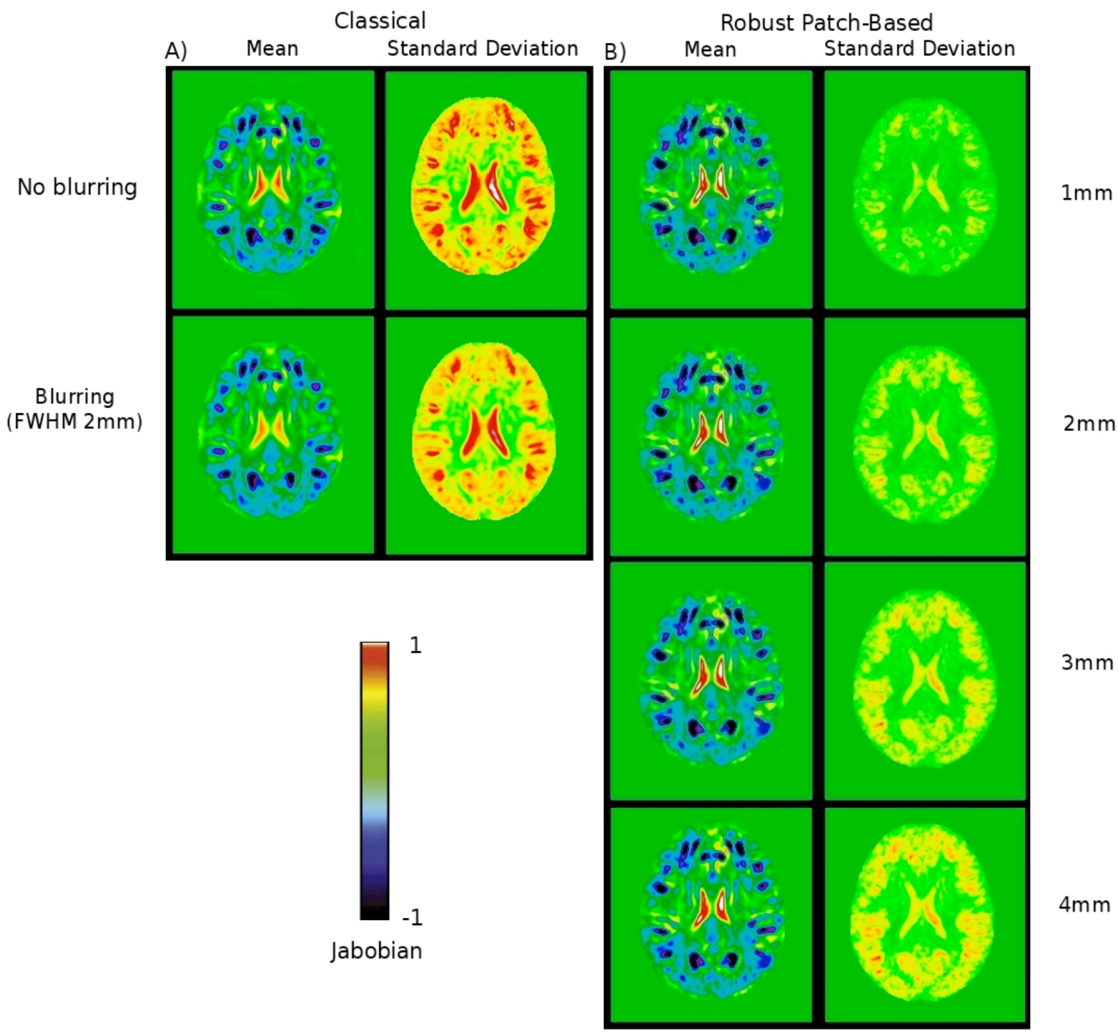

Figure 2: Mean and standard deviation of the Jabobian maps for the 20 MS patients: A) Classical mean approach without blurring and blurring (2mm Gaussian kernel) (Right) and B) Robust mean with 4 different patch sizes (1, 2, 3 and 4mm).

		Mean±std
Standard Mean		0.42 ±0.14
Blurring (FWHM 2mm)		0.38±0.13
Patch size (radius in mm)	1	0.17±0.06
	2	0.21±0.09
	3	0.24±0.09
	4	0.27±0.10

Figure 3: Statistical results for the Jacobian aggregation

Conclusion

We proposed to apply the local patch-based approach in the context of a standard DBM study. The estimation of the population Jacobian with our robust patch-based method provides more accurate results compared to the classical mean Jacobian computation and appears to identify finer anatomical differences with the reference image.

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