Inverse Consistent Geometric Flow based Nonlinear Registration Driven by Mutual Information

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Introduction: The quality of image registration plays a critical role in the quantitative MR image analysis, including tensor/voxel based morphometry. Image registration problem should be symmetric, i.e. inverse consistent and diffeomorphic for accurate morphometric measurements and maintaining the topology. Many published nonlinear registration techniques, even though are diffeomorphic, do not explicitly include inverse consistency constraint (ICC). In this paper, the ICC is implemented by alternatively minimizing the dual residual fields symmetrically with a geometric flow using Mutual Information (MI) as the similarity measure. The significant improvement in the image registration quality using this method is demonstrated.

Method: MI is used as a similarity measure in dealing with intensity differences within and between images [1]. Given two images I and J, the transformation of image J with deformation field U on I is represented by $J \circ U(p) = J(p + U(p))$ ('$\circ$' is the composition operator), where p denotes the voxel. Similarly, the transformation of an image I with deformation field W on J is represented by $I \circ W(p) = I(p + W(p))$. The MI based similarity measure between I and deformed J, is defined as $MI(I, J \circ U)$ and MI based similarity between J and deformed I, is defined as $MI(J, I \circ W)$. The symmetric inverse consistent registration alternatively minimizes the following terms:

$$-MI(I, J \circ U),\ \mathrm{Re}g(U, \partial U/\partial t),\ -MI(J, I \circ W),\ \mathrm{Re}g(W, \partial W/\partial t), \text{ and } (\|U \circ W\|^2 + \|W \circ U\|^2).$$

Here, $\mathrm{Re}g(U, \partial U/\partial t)$ and $\mathrm{Re}g(W, \partial W/\partial t)$ are regularization terms for imposing viscous constraints on the correction fields $\partial U/\partial t$ and $\partial W/\partial t$, and elastic constraints on the displacement fields U and W. $\|U \circ W\|$ and $\|W \circ U\|$ define the inverse consistency errors (ICE) (the residual fields) on images I and J, and should be close to zero for inverse consistent registration. A gradient descent method [2] was used to optimize the MI based similarity measures. Gaussian filtration with $\sigma = 1$ was used for regularizing the correction and displacement fields, and ICE was minimized by adjusting the residual fields defined on images I and J. The diffeomorphic transformation, an invertible one-to-one mapping that maintains the anatomic topology, is achieved by updating the displacement field through the composition schemes [3]. The displacement field was adjusted before and after the elastic regularization to minimize the ICE.

The above procedure was applied to register brain MR images acquired on 18 normal volunteers. Three-dimensional T1-weighted, fast field gradient echo images were acquired on a 3T Philips scanner with an acquisition matrix of 256x256x138. The resulting voxel size was 0.94 x 0.94 x 1 mm^3.

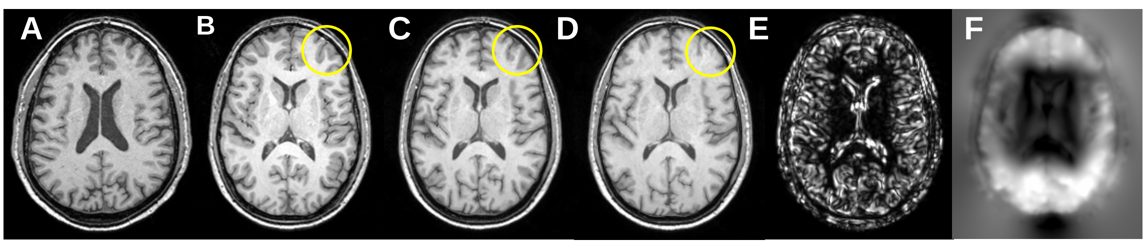

Fig. 1. Example of inverse consistent registration: (A) source image to be deformed, (B) Target image, (C) deformed source image with ICC, (D) deformed source image without ICC, (E) ICE with ICC, and (f) ICE without ICC. The intensity scales in (E) and (F) are different for better visualization.

Result: The results of proposed method on one subject are summarized in Fig. 1. In this figure, images from left to right are: source (image to be deformed), target, deformed source with ICC, deformed source without ICC, ICE with ICC, and ICE without ICC. Visually, as can be seen in the circled region, the image obtained by including ICC (Fig. 1C) is more similar to the target image (Fig. 1B) compared to the one produced without ICC (Fig. 1D). The maximum and mean ICE values with ICC were 0.05 and 0.004 voxels, respectively. The corresponding ICE values without ICC were 11.0 and 4.0 voxels. The minimum and maximum values of Jacobian determinant (JD), a measure of diffeomorphism, obtained on 18 subjects following registration with ICC are shown in Fig. 2a. Fig. 2b shows the maximum and mean ICE obtained on these subjects. The positive values of JD shown in Fig. 2a demonstrate the diffeomorphism of our registration method, and the low ICE values show the excellent performance with ICC. Compared to the recently reported ICE values with other inverse consistent methods [4, 5], our ICE values are less than one-tenth, indicating the excellent quality of the proposed registration technique. This is mainly because of the differences in the minimization procedure.

Conclusions: A diffeomorphic registration method that is inverse consistent is presented in this study. The excellent performance of this method is demonstrated on 18 normal brain MR images.

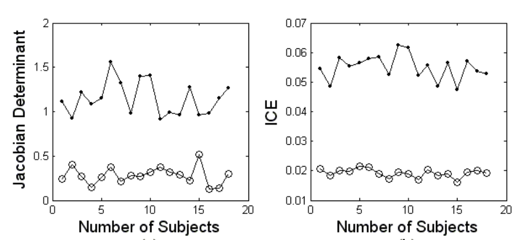

Fig. 2. Jacobian determinants (a) and ICEs (b) of registration results obtained for 18 subjects by the proposed method. The circles on (a) represent minimum JD, and dots represent (maximum JD)/2 (scaled for better visualization). The dots in (b) represent maximum ICE and circles represent (mean of ICE values)*5 (scaled for better visualization).

References

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