A consistent and topology preserving registration framework with B-spline models

Y. Chen[1], H. An[1], W. Lin[1]

[1]Radiology, The Univ. of North Carolina at Chapel Hill, Chapel Hill, NC, United States

Introduction

Medical image registration is important for performing inter-subject comparison of the imaging results. The widely utilized SPM has employed affine transformation based registration technique [1] for spatial normalizing fMRI data. The major draw back with affine registration is that only 12 parameters are used for image warping, which is generally not flexible enough to accommodate the complex geometrical difference between subjects. In contrast, B-spline based registration approaches offer great flexibility but cannot guarantee that the correct topology is maintained after warping. Tissue points may come across each other with the original proposed approach in [2]. Rohlfing et al have introduced a volume preservation constraint, which is enforced by making the determinants of Jacobian matrices close to one [3]. This is able to make the determinants to be positive for topology preservation. But for inter-subject registration, unity determinants of Jacobian matrices are hardly the case.

Another drawback with the above registration techniques is that the registration is performed uni-directionally. As a result, different registration results can be obtained between registering image A to B instead of B to A. This is clearly not desirable for statistical analysis, since consistent registration results should be obtained independent of registering image A to B or vice versa.

In this work, we propose a topology preserving and consistent registration method based upon a B-spline model. With the proposed topology constraint, there will be no topology violation in image warping. The inconsistency between the registrations performed in both directions is dramatically reduced with our method. Finally, we will demonstrate that this technique performs better than affine registration.

Materials and Methods

Two cubic B-spline models (M_f, M_b) were employed to represent the bi-directional transformations between the source and the target image pair. The image dissimilarity (C_I) is computed as the sum of squared difference between the transformed version of the image and the one to be registered to. The consistency between the transformations in both directions were enforced by including a term (C_c) computing the averaged squared sum of discrepancy distance between a voxel's original location and its location after it traveled from the source to the target and back to the source. The topology preserving constraint (C_T) is a sigmoid function which will yield almost 0 value when the determinant of Jacobian matrix is positive and 1 when the determinant is negative. The optimal transformation pair was obtained through the minimization of a weighted sum of these cost functions.

$$C_I(M_f,M_b)=\frac{1}{N_s}\sum(I_s(X_s)-I_t(M_f(X_s))^2+\frac{1}{N_t}\sum(I_t(X_t)-I_s(M_b(X_t))^2$$

$$C_c(M_f,M_b)=\frac{1}{N_s}\sum(X_s-M_b(M_f(X_s))^2+\frac{1}{N_t}\sum(X_t-M_b(M_f(X_t))^2$$

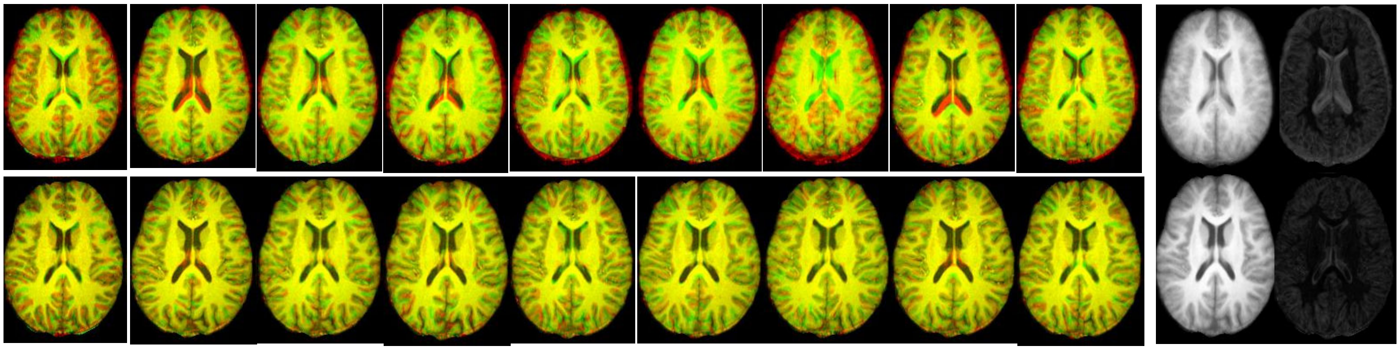
$$C_T(M_f,M_b)=\sum sigmoid(-k\cdot\det(Jac(X_s)))+\sum sigmoid(-k\cdot\det(Jac(X_t)))$$

$$M^*_f, M_b^* = \arg\min(C_I + w_C C_c + w_T C_T)$$

10 normal volunteers were scanned for anatomical T1 weighted images after written consent. One data set was arbitrarily chosen as the template for the remaining 9 data sets to be registered to. Affine registration was also carried out to compare with our proposed approach. Following registration, we also computed the mean and standard deviation of the spatial normalized images.

Results

The mean and standard deviation of the averaged inconsistency distance in both directions for the affine registration, uni-directional B-spline registration and the proposed approach are 5.59±1.73, 3.66±0.80 and 0.16±0.06 pixels, respectively. The proposed approach dramatically reduces the inconsistency between the forward and backward registration. The first 9 color images of the upper and lower panel show one transverse slice of the deformed source image (in gree) super-imposed upon the target image (in red) for all the 9 runs from affine registration and the proposed approach, respectively. The remaining two grey images are the mean and standard deviation of the normalized images from the same slice location following these two techniques to be compared. They are given with the identical gray scale. The anatomical structures in the mean image computed with affine registration is much blurred compared with our method. The proposed technique also has much less value in standard deviation compared with the affine registration.



Discussion

The proposed method eliminates the difficulties associated with the currently available registration techniques based upon B-spline models by enforcing the topology preserving and consistency constraints on both the forward and backward transformations. In addition, our results also demonstrate that the proposed approach can align anatomical structures with greater flexibility than affine registration, suggesting that this approach could replace the registration method imbedded within SPM for more accurate spatial normalization.

References

[1] Maes, et al IEEE-TMI 16, 187-98, 1997. [2] Rueckert, et al IEEE-TMI Vol 8, No.8, 1999. [3] Rohlfing, et al IEEE-TMI, Vol. 22, No. 6, 2003