

Registration of Postmortem Brain Slices to Matching MR Slices within 3D Reference MRI

Tae-Seong Kim¹, Manbir Singh², Nilesh Ghugre², Sungheon Kim², Chris Zarow³, Helena Chui³

¹University of Southern California, Alfred E. Mann Institute For Biomedical Engineering, LA, CA USA; ²University of Southern California, Depts. of Radiology and Biomedical Engineering, LA, CA USA; ³University of Southern California, Department of Neurology, LA, CA USA;

Introduction

Registering postmortem brain slices to their corresponding in-vivo MR slices can provide additional pathological information not obtainable from postmortem slices alone. However geometrical distortions and difficulties in reconstructing the brain volume from postmortem slices [1] make this task difficult and challenging. In our previous study, we derived a slice-to-volume transformation to register each postmortem slice to its matching MR slice within a 3D reference MRI based on a minimum mean-squared error criterion [1,2]. In an ongoing effort to improve registration, in this study we employed and tested eight different voxel similarity measures that are commonly used in image registration [3]. The registration algorithms were evaluated with simulation studies where the "ground truth" is known. Then each similarity measure was applied to real postmortem and MRI data and evaluated based on difference images and a count of the mismatched voxels [4]. The results of this comparison of the similarity measures are presented in this paper.

Methods

Preprocessing of Postmortem and Volume MRI

To match the setting of postmortem slices, the brain was extracted from the skull and scalp in 3D MRIs. Preprocessing details of postmortem slices and 3D reference MRIs are available in our previous papers [1,2].

Image Transformation

Nonlinear distortions in postmortem images are mainly introduced from mechanical slicing, ventricle collapsing, dehydration, and pathological deformations. To compensate distortions, image warping is essential. We incorporated image warping by transforming 2D slice coordinates to warped slice coordinates in 3D using modified nth-order polynomials [1,2]. Second-order compensation was utilized in this study.

Voxel Similarity Measures

Registration cost functions were devised using the following voxel similarity measures as summarized in [3] to measure how a given target image matches a recursively-derived warped slice from a 3D MRI:

1. Mean-Squared Difference (MSD)
2. Mutual Information (MI)
3. Normalized Mutual Information (NMI)
4. Cross Correlation (CC)
5. Entropy of Difference Image (EDI)
6. Pattern Intensity (PI)
7. Ratio Image Uniformity (RIU)
8. Modified RIU (MRIU)

Mathematical descriptions of each similarity measure are given in [3].

Registration Algorithm

An initial image was selected by computing the MSD between a target postmortem slice and each MR slice in the same orientation as the postmortem slice (in this case coronal). Once the algorithm was initialized with an image that produces the lowest MSD, the best matching image was derived by estimating the coefficients of transformation that minimize or maximize each similarity measure. The simplex optimization and trilinear interpolation methods were used. Details of the registration algorithm are also given in [1,2].

Results and Discussion

Validation and Accuracy of Algorithm

To validate the algorithms and measure the accuracy of each registration cost, we conducted simulation studies using only a brain-extracted 3D volume MRI. Since the performance of each measure depends on the nature of data [3] and it is not possible to model all distortion factors in postmortem slices, a quantitative measure of accuracy was set by extracting a MR slice from a 3D MRI with known coordinate transformation coefficients of 2nd-order. Using this selected image as a target slice for registration, a matching slice within

a MR volume was found with each similarity measure. Then the displacement of each voxel in Euclidean distance with known and estimated coordinates was computed. Using this procedure, the results of the mean of voxel displacements for each similarity measure were: MSD=0.018, MI=0.029, NMI=0.026, PCC=0.011, EDI=0.214, PI=0.007, RIU=1.001, and MRIU=36.228. All similarity measures performed well except voxel uniformity measures (RIU and MRIU) within a threshold of acceptable subvoxel accuracy.

Registration of Postmortem Slices to Volume MRI

The algorithms were also applied to real postmortem slices and a reference 3D MRI of the same subject. Since postmortem images contain unknown dimensions of distortion and we do not know their true matching slices within a 3D MRI, we examined registered images via visual inspection of identical anatomical landmarks, subtraction images, and the count of mismatched voxels [4].

Figs. 1 (b-h) show the registered MR slice to the postmortem slice shown in Fig. 1 (a), and Figs. 1 (i-k) show the difference images for a few cases. As indicated by the gray-scale bar, positive differences are shown brighter and negative differences darker than the mean gray background. The number of mismatched voxels was determined by counting voxels within the brain that differ in difference intensity >20% of the mean intensity as defined in [4]. The counts were: MSD=2206, MI=2039, NMI=2019, PCC=2152, EDI=2236, PI=2547, and RIU=2908. This suggests that NMI and MI lead to similar results and produce the smallest number of mismatched voxels.

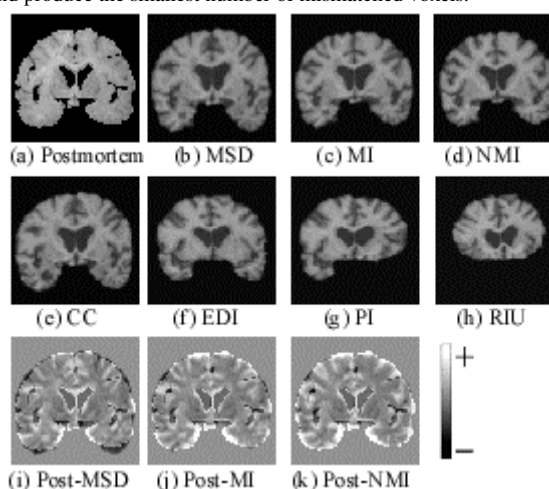


Fig. 1: (a) original postmortem image (b-h) the registered MR slice obtained through different algorithms (i-k) difference images: postmortem-MSD, postmortem-MI, and postmortem-NMI.

Conclusion

We found that similarity measures based on mutual information produce the best results, both through a visual anatomical comparison and through a quantitative count of mis-matched voxels, for registering postmortem slices to their corresponding MR slices. This confirms other studies of utilizing mutual information measures [5,6] for registering multi-modality medical images.

References

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