A Method for Validation of 3D Nonrigid Image Registration Algorithms

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Abstract

A method for validation of nonrigid 3D image registration algorithms is presented and compared to a manual validation strategy. The method provides pairs of deformed images as well as corresponding true displacement fields with known accuracy. Nonrigid registration algorithms can be run on the pairs of images and their outputs can be compared to the true displacement fields. The output of the method was compared to the displacements generated manually by five observers. The study showed that the observers, when averaged, were able to come close in accuracy to the presented method in image regions with strong features, while they generated less accurate results in image regions with poor or no features.

Introduction

One of the challenges in the development of image registration algorithms is their validation. In most practical situations it is either not possible or it is very difficult to obtain ground truth data for validation of non-rigid image registration ([1], [2]). In this work we address the problem of validation of nonrigid image registration algorithms. Ideal validation data for image registration of two images should have the true displacement vector for each point of the first image that would bring it to the corresponding point in the second image. In addition, the accuracy of the data has to be known, since validation data without known accuracy is useless.

3D Validation Data

To generate ground truth data for validation of 3D nonrigid image registration algorithms a deformable physical model was used. The model was imaged in an MRI scanner, physically deformed, imaged in the deformed state, and two more times deformed and then imaged. The model was made of two types of modeling clay and small pieces of carrot. The three components have different MR signals, which made contrast in the images and simulated anatomical structures. In addition, 20 small glass beads were placed throughout the volume of the model, which purpose was to serve as validation points. The model in pre-deformation and three deformed states is shown in Fig. 1. The images were acquired at Emory University Hospital using a Siemens Magnetom Trio MRI 3 Tesla scanner with the following parameters: 256 x 256 x 72 voxels, voxel size 0.55 mm x 0.55 mm x 1.0 mm, TR = 2500 ms, TE = 4.4 ms, TI = 1100 ms, FOV = 140 mm, flip angle = 8 deg, 4 averages over signal acquisition. We have developed a method for automated computation of the bead locations based on a template matching approach. The size of the beads was about 2 x 2 x 2 mm, which means that their location can be determined with an accuracy of 1 mm in each direction. Because the beads show up as clear dark voids in the images, they provide additional “artificial” strong image features for nonrigid image registration. In order to provide only “natural” image features we interpolated the surrounding voxel intensities over the bead voxels (Fig. 2). Images with removed beads can be used to test 3D nonrigid image registration algorithms, while the bead locations can be used as validation points.

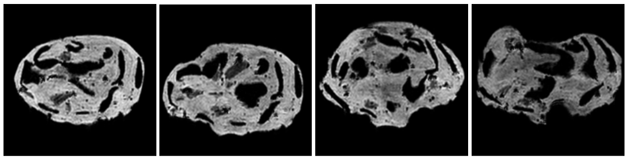
(a) (b) (c) (d)

Fig.1. A section through the 3D MRI volume of the undeformed model (a), after first deformation (b), after second deformation (c), and after third deformation (d)

Manual Validation

The goal of this study was to assess the accuracy of manual validation and to analyze variability among observers. Five observers were asked, for 20 points in the undeformed image, to find the corresponding points in the deformed image. The results are summaried in Table 1. The mean errors in x, y and z direction are between -0.1 and 0.3 mm, while the maximal error is 6.7 mm in x direction for one of the points. Due to the proximity of a dark small region to a bead, observers may have mistaken the dark region for the bead. The std is highly correlated with the mean error magnitude, and the correlation coefficient between these two variables is .96. To test the ability of the data provided by the observers, we removed one of the observers from the statistical analysis and the results didn't change significantly. This showed that the observers provided approximately equally accurate data.

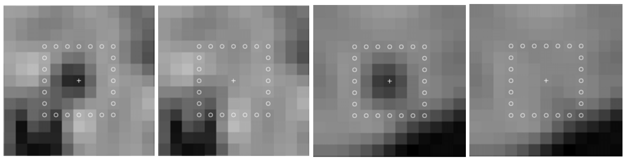
(a) (b) (c) (d)

Fig.2. A 2D section through a bead before (a) and after (b) bead removal via interpolation. Another bead removal example is shown in (c) and (d). The white circles represent the voxels used for interpolation of the bead voxel. The white cross represents the central bead voxel.

Discussion

The method for obtaining validation data for 3D nonrigid image registration algorithms is similar to computer simulations in the sense that the deformation is artificial. However, the images are obtained using a real acquisition system, rather than applying a mathematical model. The analysis of the manual validation showed that the observers, when averaged, were able to come close in accuracy to the automated methods for points located at strong image features, while they produced less accurate results for points in image regions with poor or no features. At the other hand, the automated method generates equally accurate validation data everywhere in the image regardless of the strength of the image features. These conclusions can be used as guidelines when designing validation strategies for nonrigid image registration algorithms based only on the input of observers. While this phantom validation study doesn’t provide physically correct deformations, it’s certainly a useful way to test the algorithm’s ability to recover various deformation patterns.

References

1. Christensen, G.E, "Minimizing sources of errors in medical image registration", Proceedings. 2002 IEEE International Symposium on Biomedical Imaging, pp. 14-17, 2002
2. Julia A. Schnabel, Christine Tanner, Andy D. Castellano Smith, et al., "Validation of Non-rigid Registration Using Finite Element Methods", IPMI 2001. pp. 344-357, 2001

Table 1. The mean and maximum value of the average error for four abservers in x direction, e_x, y direction, e_y, z direction , e_z, error magnitude, $||e||$, and standard deviation, Std, over the twenty markers. All values are in millimeters

Case	e_x mean/max	e_y mean/max	e_z mean/max	$\|\|e\|\|$ mean/max	Std Mean/max
1	-0.1/6.7	0.0/2.1	0.3/2.6	1.5/6.7	1.4/10.8