Validation of 3D Non-rigid Whole Body MR Image Registration

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Introduction

The automatic registration of whole body MR images, which requires non-rigid registration techniques of articulated structures, remains a challenge. Although, in recent past, we have proposed a promising registration method that permits the automatic registration of MR images [1], one weakness was identified in this algorithm: bones could be deformed incorrectly because of the surrounding structures. A modified method was proposed in [2], which can constrain the deformation of bony structures. In this paper, we present a validation study that shows that our approach could be used for the automatic segmentation of MR images.

Methods

The previously proposed algorithm works on co-registered MR-CT pairs. To register one mouse to the other, several steps are used. First, skeletons are extracted from the CT images. These are then registered using a robust point-matching algorithm [3]. The transformations computed with the skeletons are then applied to the MR images. The transformations are then refined by applying an intensity-based non-rigid registration algorithm [4] to these MR images. Local mechanical properties of the transformation can be adjusted to produce, for instance, transformations that are stiffer over bony regions than over soft tissue regions. This can be done by adapting spatially the regularization of the transformation and by adding a term to the similarity measure that penalizes the displacement of bones as follows:

$$F_{\text{cost}} = -\frac{H(A)+H(B')}{H(A,B')} + \lambda \frac{1}{N}\sum_i d(p_i)\,, \qquad (1)$$

where the first term is the standard negative normalized mutual information and the second term is the mean displacement of all voxels on the bones. To minimize this cost function, the algorithm thus needs to limit the deformation of the bony structures while maximizing the similarity between images in the soft tissue region.

To acquire the images, a mouse was first sacrificed and imaged in a Varian 7.0T. MR images were obtained with a spatial resolution of $0.176\text{x}0.25\text{x}0.25\text{mm}^3$. Next the mouse was imaged within the same holder using an Imtek MicroCAT II small animal scanner to generate the CT images with a resolution of $0.2\text{x}0.2\text{x}0.2\text{mm}^3$. The mouse posture was then changed arbitrarily and a second set of MR and CT scans were acquired. This process was repeated in four mice. 17 Inter-subject data were selected through combining different mice from these four data sets.

Validation results

To validate this modified algorithm on the bony structures, the distance of the skeleton surface is calculated for every pair of data, after applying the algorithm. The mean errors of the bony structures for longitudinal study (intra-subject) and for the registration between different mice (inter-subject) are 0.244mm and 0.297mm, respectively. These small errors indicate a satisfactory registration of the bones.

To validate on the soft tissues, the contours of hearts, two kidneys, and bladder are segmented manually in the source and target images. The contours in the source images are transformed using the deformation field generated by the algorithm, and the Dice values are calculated as Dice = $2\times\frac{n\{A_1\cap A_2\}}{n\{A_1\}+n\{A_2\}}$, where A_1 and A_2 are two regions and $n\{\,\}$ is the number of voxels in a region.

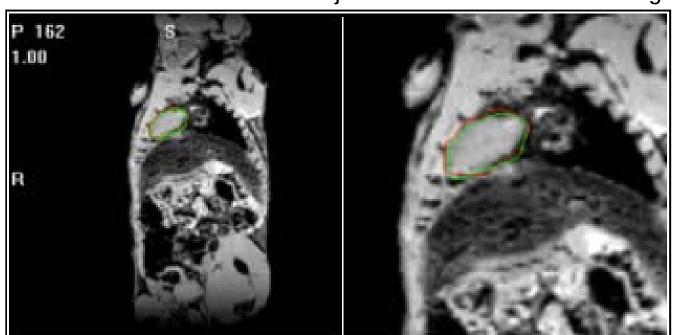

Fig. 1: The target image overlaid with automatically deformed contour (green), and contours segmented manually (red). The Dice value between contours is 0.91 in this image.

Table I: Mean Dice values for four soft tissues. A Dice value of above 0.7 is customarily accepted as a value for which two contours are in very good correspondence.

	Intra-subject	Inter-subject
Heart	0.9022	0.8318
Left Kidney	0.9150	0.8281
Right Kidney	0.9134	0.8380
Bladder	0.8456	0.4140

Fig. 1 shows an example with manual and automatic contours superimposed. TABLE I lists the mean Dice coefficients of soft tissues for four intra-subjects and 17 inter-subjects. The high Dice values for the intra-subject indicate the excellent agreement between the automatic deformation and manually delineation, which also means the accurate registration results. The values for the inter-subject are lower, compared with the intra-subject; this is expected because the inter-subject registration is a more difficult task, due to the morphological differences. Moreover, we find the bladder is the hardest tissue to register, which is most likely due to the volume of urine that is in the bladder at the time of imaging.

Conclusions

In this work, an improved method is introduced for the automatic registration of whole body MR images. Several data sets are used to validate this algorithm on bones and soft tissues. The validation results show that the algorithm leads to accurate registration results for both intra- and inter-subject registration tasks.

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References 1. Xia Li et al., ISMRM07. 2. Xia Li et al., SPIE07. 3. Haili Chui, et al., Computer Vision and Image Understanding 89 (2003).
4. Gustavo K Rohde, et al., IEEE Trans. Med. Img. Nov. 2003.