EVALUATION OF AN INTENSITY-BASED FREE-FORM DEFORMABLE REGISTRATION ALGORITHM

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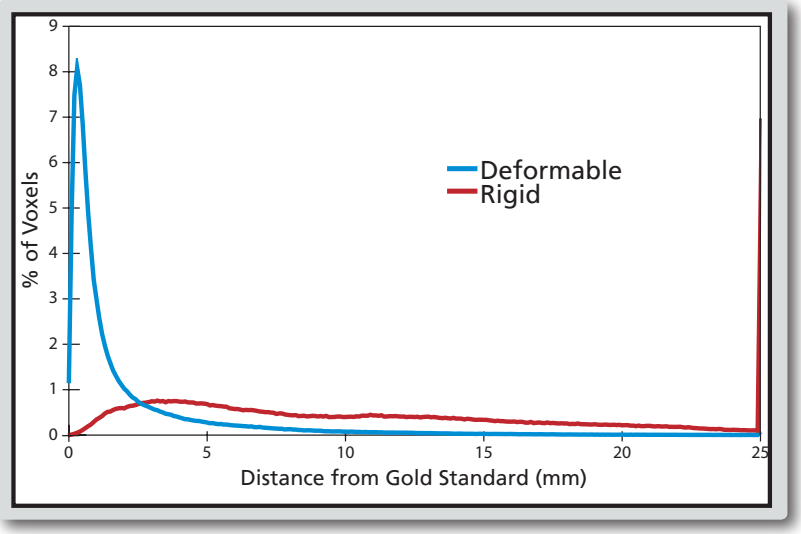
Purpose

To propose and evaluate an intensity-based free-form deformable registration algorithm for CT image volumes.

Method and Materials

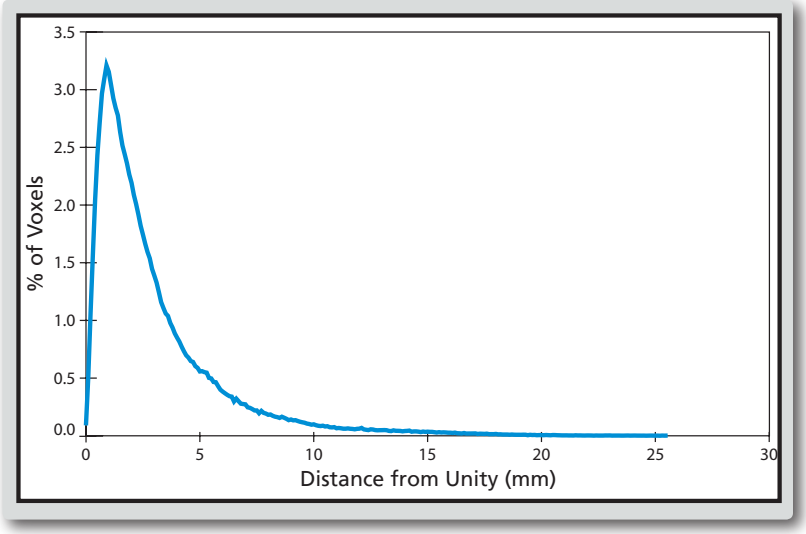
We have developed an intensity-based deformable registration algorithm with essentially limitless degrees of freedom depending on required accuracy and execution speed. The algorithm utilizes sufficient regularization to minimize the likelihood of folds or tears in the deformation fields. The first evaluation strategy utilized real CT volume pairs acquired weeks apart for three subjects who exhibited significant weight loss during IMRT treatment. For these subjects, we calculated the correlation coefficient after rigid and deformable registration. For the second evaluation strategy, a known deformation was applied to a real CT volume creating a synthetic target to determine the ability of the algorithm to recover the same "gold standard" deformation. For the final evaluation, we measured the consistency of the algorithm as the average distance of concatenated forward and reverse deformations from the unity transform on a real CT volume pair.

Figure 1
Error Distribution for Synthetic Target



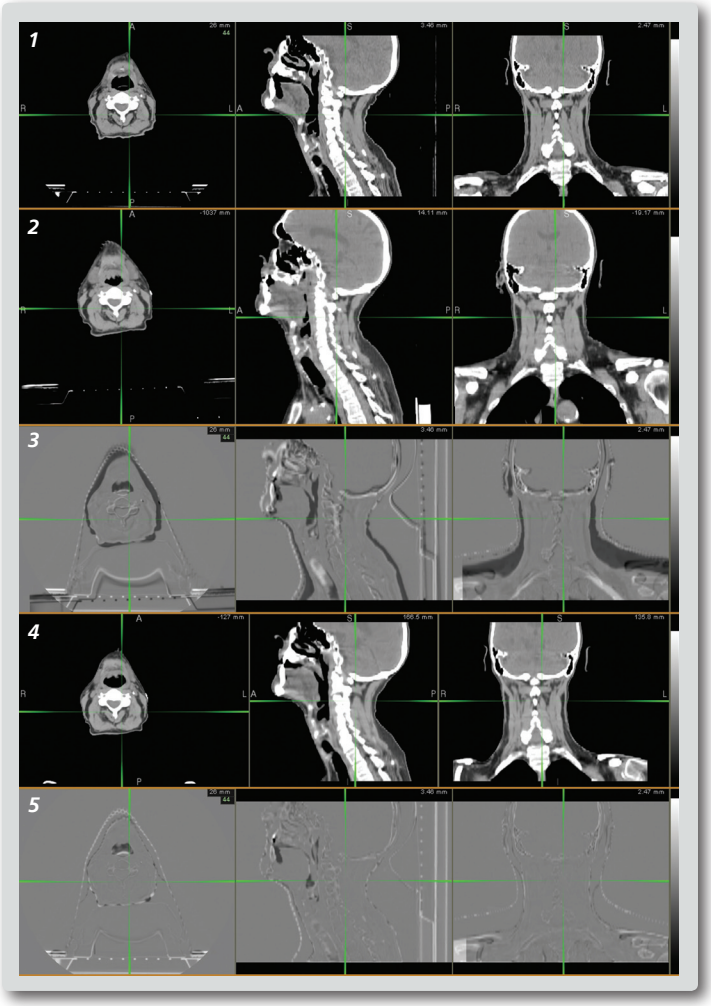
The free-form deformable registration recovered the known transformation much better than rigid registration. The median and mean residual error was ten times better for the deformable registration at 0.8mm and 1.1mm (1.9mm SD) compared with 9.3mm and 10.3mm (6.6mm SD), respectively.

Figure 2
Consistency Error Distribution



Consistency refers to the ability of a transform to obtain the inverse transform in a reverse registration. Concatenating the forward and reverse deformations resulted in a median and mean distance from unity of 2.1mm and 3.1mm (3.1mm SD), respectively. This result was obtained in the absence of any constraints to encourage consistency.

Figure 3
Residual Intensity Differences



Shown are (1) the target CT image, (2) the original CT image, (3) subtraction after rigid registration only, (4) the deformed CT image, and (5) subtraction after deformable registration. The residual intensity differences, which appear brighter or darker than neutral gray, are significantly reduced after deformable registration compared with rigid registration.

Results

The correlation coefficients after rigid registration were 0.890, 0.921, and 0.859 for the three volume pairs. These improved to 0.979, 0.983, and 0.978, respectively, after deformable registration. These results were comparable to benchmark self-correlations of the target CTs with a 1.4mm translation error applied (0.979, 0.980, and 0.978, respectively). In the second experiment, rigid registration averaged 10.3mm error (6.6mm SD) while deformable registration averaged 1.1mm error (1.9mm SD) from the "gold standard". Nearly three quarters (73.9%) of voxels had less than 1mm error and the 95% confidence interval was 4.8mm compared to 0.6% and 23.2mm respectively for rigid registration. Finally, concatenating the forward and reverse deformations resulted in an average distance of 3.1mm (3.1mm SD) from unity

Conclusions

The accuracy and speed of the algorithm suggests its utility for a variety of purposes including integration into an adaptive radiation therapy protocol.

Piper JW. Evaluation of An Intensity-Based Free-Form Deformable Registration Algorithm. Medical Physics. June 2007;34(6):2353-2354.