AAPM 46th Annual Meeting, 2004

Accommodating Bowel Gas in Large Deformation Image Registration for Adaptive Radiation Therapy of the Prostate*

B. Davis, D. Prigent, J. Bechtel, J. Rosenman,
D. M. Lovelock†, S. Joshi

MIDAG
University of North Carolina, Chapel Hill

†Memorial-Sloan Cancer Center
New York, NY

Abstract

We have been developing methods for adaptive radiation therapy of the prostate that use large-deformation image registration to automatically track organ motion between inter-treatment CT images. The presence of bowel gas in pelvic CT data can cause significant errors in image registration because no correct correspondence exists between an image that contains gas and one that does not. In order to accommodate bowel gas and improve the accuracy of image registration for adaptive radiation therapy, we propose a novel method for deriving image-to-image correspondence that includes steps for segmenting and deflating bowel gas prior to image registration. First, simple thresholding is used to create a binary image of gas present in the rectum. A non-diffeomorphic deflation transformation is then estimated by generating a flow driven by the gradient of this binary image. The gradient is only non-zero at the boundary of the binary regions, so the gas is effectively deflated like a balloon. Finally, the deflated images are accurately registered using previously developed image registration algorithms. Current research shows that for images without gas, these algorithms are accurate to within 1.5mm. Correspondence between the original images is estimated by concatenating the resulting registration transformation with the appropriate gas deflation transformations. Once this method is used to establish correspondence, delineated anatomical structures are mapped between images, allowing for the analysis of organ morphology. These correspondences are also used to accumulate inter-fraction dose in a common coordinate system. We present results of applying this method to inter-treatment pelvic CT data.

*Presented at AAPM Annual Meeting, Pittsburgh, Pennsylvania, July 2004.

Accommodating Bowel Gas in Large Deformation Image Registration for Adaptive Radiation Therapy of the Prostate

Introduction: One of the major challenges in adaptive radiation therapy is the estimation of accurate correspondence between inter-treatment images. This correspondence can be used to study organ motion and to accumulate inter-fraction dose. We have been using large deformation image registration to estimate correspondence between images. In prostate images, however, the presence of bowel gas can cause significant correspondence errors as the registration algorithm attempts to expand or contract image regions to match pockets of bowel gas. To account for this problem, we present a novel method that combines large deformation image registration with a bowel gas segmentation and deflation algorithm.

Methods: As the contrast between gas and surrounding tissue is very high in CT images, we create a binary segmentation of the gas in an image using a simple thresholding operation . We refine this binary segmentation using a morphological open operation. Next, we construct a deflation transformation s based on a flow induced by the gradient of the binary image. Points along the gas-tissue border, where the gradient is non-zero, flow in the direction of the gradient. As a result, gas filled regions collapse toward their medial skeletons—deflating like a balloon.

More precisely, we consider an image $I(x)$ with associated coordinate system Ω, $x = (x_1, x_2, x_3) \in \Omega \subset \Re^3$. We construct a non-diffeomorphic deflation transformation $s : \Omega \to \Omega$ such that $I(s(x))$ is the image $I(x)$ after a deformation that deflates gas. s is constructed by integrating velocity fields $v(x, t)$ forward in time, i.e. $s(x) = x + \int_0^1 v(s(x, t), t)\, dt$. These velocity fields are induced by a force function $F(x, t) = \nabla(I \circ s_t)(x)$ that is the gradient of the binary image. The force function and velocity fields are related by the modified Navier-Stokes operator $(\alpha\nabla^2 + \beta\nabla\nabla \cdot +\gamma)v(x, t) = F(x, t)$. We solve for s using an iterative greedy method.

After deflating bowel gas, images can be accurately registered. We apply the theory of large deformation diffeomorphisms [1] to generate a deformation $h : \Omega_1 \to \Omega_2$ that defines a voxel to voxel correspondence between the two images I_1 and $I_2 \circ s$ [2]. Correspondence between the original images I_1 and I_2 is estimated by concatenating the registration and deflation transformations, i.e. $s \circ h : \Omega_1 \to \Omega_2$. This composite transformation is not guaranteed to be diffeomorphic. However, the non-diffeomorphic part of the transformation is restricted to the region of the rectum that contains gas—where no correspondence exists.

Results: All experiments were carried out on 3D intra-patient pelvic CT data. Figure 1 shows an axial slice from rigidly aligned reference and daily images. In this case, correspondence between the reference and daily images is estimated using only large deformation image registration. This correspondence is used to map manually drawn contours of the prostate and rectum from the reference image onto the daily image. Manual contours are drawn in red while mapped contours are drawn in yellow. Notice the misalignment of the manual and automatically generated contours in the daily image; the presence of bowel gas has

Reference Image　　Registered Daily Image　　Daily Image

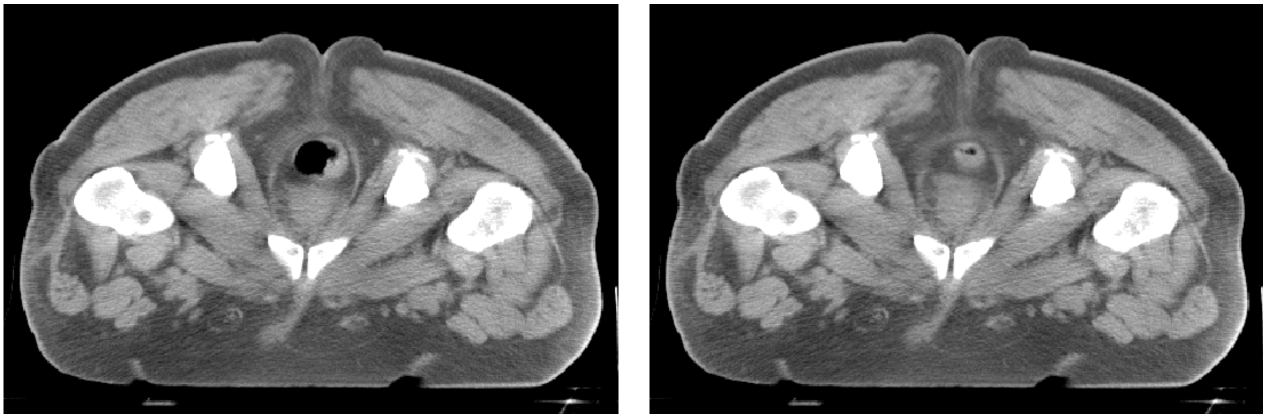
Figure 1: Correspondence is estimated between the reference and daily image without accounting for bowel gas. This correspondence is used to map manually drawn contours of the prostate and rectum from the reference image onto the daily image. Manually drawn contours are shown in red and mapped contours are shown in yellow. Notice the misalignment of the manual and mapped contours near the bowel gas in the daily image.

caused correspondence errors around the rectum. Figure 2 shows the result of our gas deflation algorithm. The large pocket of gas present in the daily image has been deflated, resulting in an image that can be accurately registered to the reference image. Figure 3 shows the result of the method presented in this paper. A more accurate correspondence between the reference and daily images is established by concatenating registration and deflation transformations. Notice the close alignment between the manual contours and the contours generated by our method. We plan a statistical analysis of these results, including measurement of contour overlap statistics, inter-patient variability, and inter-rater variability.

References

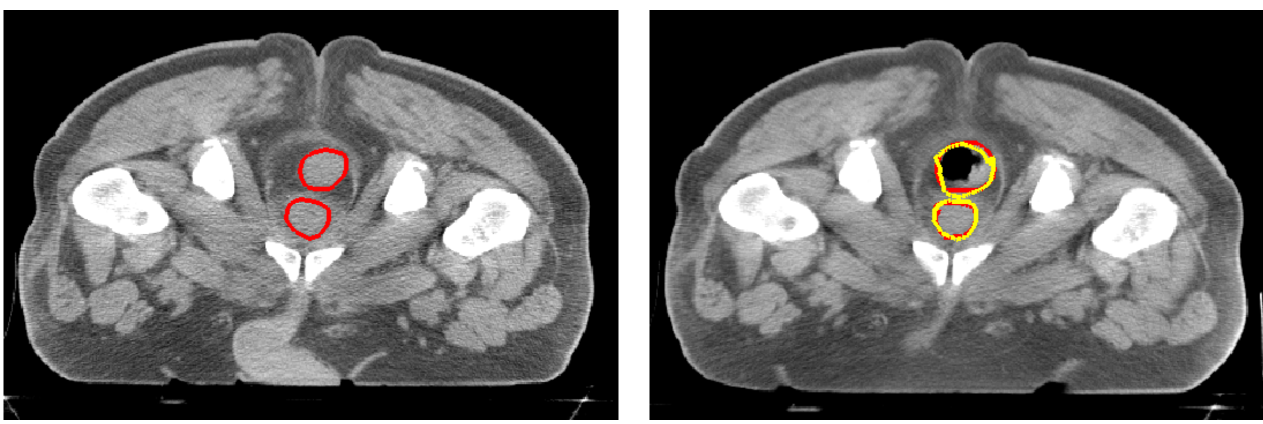
[1] Michael I. Miller, Sarang C. Joshi, and Gary E. Christensen, "Large deformation fluid diffeomorphisms for landmark and image matching," in *Brain Warping*, Arthur W. Toga, Ed., chapter 7. Academic Press, 1999.

[2] Brad Davis, Peter Lorenzen, and Sarang Joshi, "Large deformation minimum mean squared error template estimation for computational anatomy," in *ISBI (Accepted)*, 2004.



Daily Image   Deflated Daily Image

Figure 2: Demonstration of our gas deflation algorithm: the gas in the daily image is deflated. The deflated image can be accurately registered to the reference image.



Reference Image   Daily Image

Figure 3: Demonstration of our method for accounting for gas while estimating correspondence. The reference image has been registered to the deflated daily image shown in Figure 2. Correspondence between the reference and daily image is established by concatenating the registration and deflation transformations. Notice the close agreement between the manual (red) and automatically generated (yellow) contours in the daily image.