

Modeling Liver Motion and Deformation During the Respiratory Cycle Using Intensity-Based Free-Form Registration of Gated MR Images

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Introduction

Stereotactic radiosurgery has been used to treat cranial lesions for more than a decade. This type of image-guided procedure matches preoperative image data and the physical space occupied by the patient using the fact that the brain inside a closed cranium is approximately rigid. We are interested in treating extracranial lesions such as metastases and primary tumors in the liver. Abdominal targets typically move 10-30 mm during relaxed respiration. One approach is to acquire images during respiration to obtain a blurred target and/or to draw a large margin around the lesion to account for position uncertainty during respiration. Tissue motion tracking and respiratory gating of radiotherapy can potentially allow for increased radiation dose to the tumor while minimizing the dose to healthy tissue. We are interested in using kinematic models of motion to determine an appropriate gating window during which the position of the target is known within a specified excursion. In this paper, we demonstrate a technique for modeling liver motion during the respiratory cycle using intensity-based free-form deformation registration of gated MR images.

Methods

We acquired 3-D MR images of the abdomen of several volunteers at end-inhalation, end-exhalation, and five time points in between using respiratory gating. We computed the deformation field between the inhalation and exhalation images using intensity-based affine and non-rigid registration algorithms that optimize normalized mutual information [1, 2]. The non-rigid transformation is a free-form deformation with B-spline interpolation between uniformly-spaced (typically 20 mm spacing) control points [3]. The affine and free-form deformation transformations between inhalation and exhalation were visually inspected. This was performed using various image fusion techniques including the overlay of iso-intensity contours and edges extracted from the inhalation image using the Sobel operator onto the exhalation image. Transformations for the intermediate time points were also calculated both by registration and temporal interpolation of the inhalation-exhalation transformation. The intermediate transformations were also visually inspected.

Results

The liver moves by up to 25 mm. Thus unregistered images are clearly misaligned. In our volunteers, much of the liver motion is cranial-caudal translation, and thus the affine transformation captures much of the motion (Fig. 1). But there is still substantial residual deformation that the affine transformation does not account for. The spline-based free-form transformation produces a deformation field that appears on visual inspection to be very accurate (Fig. 2). This is true for the liver surface, internal liver structures such as the vascular tree, and the external skin surface. Temporally intermediate images interpolated from fractional application of the inhalation-exhalation deformation field also showed excellent consistency with the real intermediate images.

Discussion

We believe that this work is the first effort to predict abdominal organ motion and deformation due to respiration from volumetric image data using intensity-based non-rigid image registration rather than using explicit mechanical models. It therefore achieves its goals without time-consuming segmentation and does not rely on assumptions about tissue properties. Nevertheless, the deformation field derived from intensity-based non-rigid registration can easily be applied to 3-D surface models if a particular application requires that. For example, matching a deformed skin surface model with range data could enable the prediction of internal organ motion from physical-space observations. We have demonstrated that abdominal organ motion due to respiration can be satisfactorily modeled using an intensity-based non-rigid image registration approach. This allows for an easier and potentially more accurate and patient-specific deformation field computation than physics-based models using assumed tissue properties.

References

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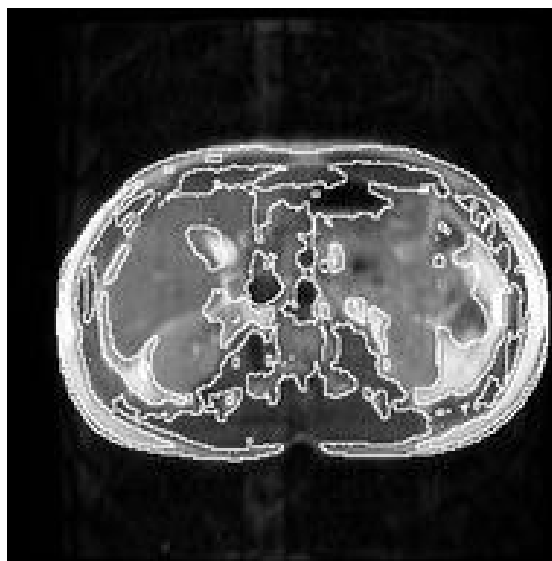


Figure 1

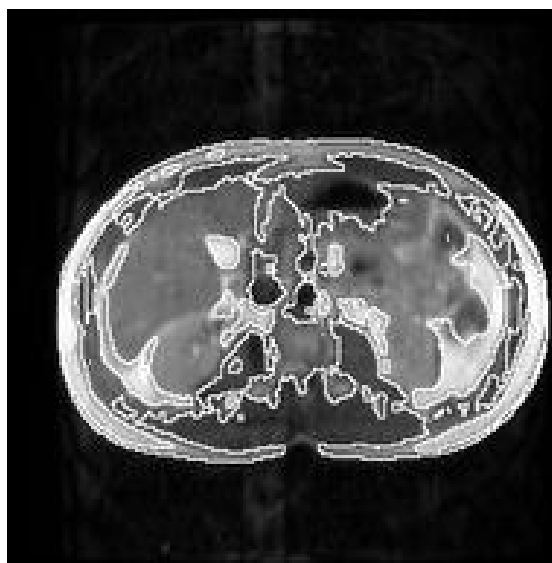


Figure 2

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