Four-dimensional cone-beam CT imaging using displacement vector fields extracted from deformable image registration: Phantom Study

Nesreen Alsbou+, Salahuddin Ahmad*, Imad Ali*

+Department of Engineering and Physics, University of Central Oklahoma, Edmond, OK

*Department of Radiation Oncology, University of Oklahoma Health Sciences Center, Oklahoma City, OK

Introduction: Patient respiratory motion and anatomical variations represent major challenges in CT imaging, treatment planning and dose delivery for cancer patients treated with radiation therapy. Patient motion induces image artifacts which degrades the CT image quality and leads to uncertainties in outlining the tumor and organs-at-risk. The variations in CT number values affects the accuracy of dose calculation in the treatment planning process. The anatomical variations induced by respiratory motion lead to changes in the position of the tumor that affect the accuracy of patient setup and tumor localization during dose delivery. The purpose of this study is to extract the motion trajectory on a voxel-by-voxel basis from the displacement vector fields (DVF) obtained from deformable image registration (DIR) from the average CT image to reconstruct 4D-cone-beam CT images (CBCT).

Methods: The cone-beam CT (CBCT) images for a thorax mobile phantom that moves with sinusoidal motion patterns with different amplitudes ranging from 0-20 mm and frequencies 0-0.5 Hz were acquired using and on-board image on a Trilogy Varian machine. The thorax phantom has three target inserts with different lengths that include: small (10 mm), medium (20 mm) and large (40 mm) that are water equivalent embedded in low density lung phantom. The CBCT images for the phantom moving with different motion patterns were registered with different deformable image registration algorithms to the CBCT of the stationary phantom. An algorithm was developed to use the DVFs extracted from deformable image registration to build the motion trajectory of the voxels of the mobile targets in the phantom. 4D-CT images were reconstruct from the average CT images for each voxel of the mobile targets and surrounding tissues in the mobile that represent the different phases of motion.

Results: 4D-CBCT images were reconstructed from the average CBCT images that covers all phases of the motion cycle. This algorithm eliminated image artifacts induced by sinusoidal cyclic motion in the reconstructed 4D-CBCT images (Fig1a). The DVF obtained from the deformable image registration were used to reconstruct a motion model on a voxel-by-voxel basis in the mobile phantom (Fig.1c-d). The maximal and minimal shifts calculated from the DFVs correlated with the motion amplitude applied on the mobile phantom. The motion amplitude and frequency were extracted from the distributions of the DVF (Fig.1e). The CT-images can be represented on a certain motion phase which provided more accurate volumes for the tumor and organs at risk used for treatment planning of cancer patients. The algorithm produced accurate CT number values of the mobile targets in the CT images of the mobile phantom.

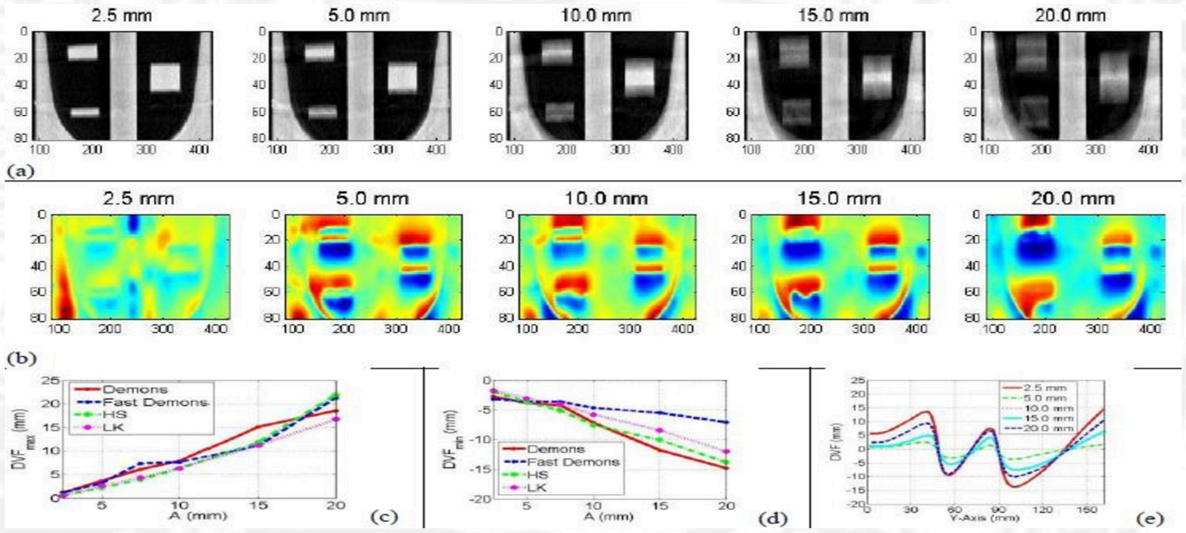

Figure 1: (a) Image artifacts in cone-beam CT images induced by phantom motion with different motion amplitudes as indicated. (b) Displacement-vector-fields maps calculate by the deformable image registration algorithm for the images in (a) with different motion amplitudes (c) The 4D-optimized dose profiles (dotted and dashed curves) corrected for artifacts from cyclic respiratory motion with motion amplitudes 10-30 mm. The dose profiles (solid black) represent 4D-optimized dose profile for stationary targets.

Conclusion: The approach developed in this study provides an alternative for conventional 4D-CBCT imaging that is obtained by tracking an external marker. The 4D-CBCT images represent patient motion on a voxel-by-voxel basis that is obtained by considering a motion model. The motion artifacts and anatomical changes were reduced significantly in the reconstructed 4D-CBCT images. This algorithm has clinical application in respiratory motion management and image guided radiation therapy.

E-Mail: nalsbou@uco.edu

The University of Oklahoma HEALTH SCIENCES CENTER

Peggy and Charles STEPHENSON CANCER CENTER at The University of Oklahoma