

Purpose: Conventional in-room Cone-beam CT (CBCT) lacks explicit motion representation and usually has poor image quality and inaccurate CT numbers for target delineation and/or adaptive planning. While in-room 4D-CBCT image acquisition is still time-consuming and suffers same poor image quality issue, the goal of this study was to develop a computational procedure to digitally synthesize high-quality daily 4D-CBCT images by taking advantage of the prior knowledge of motion and appearance defined in the planning 4D-CT dataset.

Methods: We first estimated the respiratory motion from planning 4D-CT by performing deformable image registration between the averaged planning 4D-CT to each of the phases. The resultant displacement motion vectors were further analyzed by Principal Component analysis (PCA) to construct a patient-specific low-dimensional motion model. Subsequently, dense correspondences were established across voxels of daily 3D-CBCT and averaged 4D-CT. Given voxel-by-voxel correspondences, both the learned prior motion model and CT numbers from the planning CT were spatially mapped onto the grid of daily CBCT. The transferred motion model allows us to synthesize 4D-CBCT images with a substantially improved image quality compared to the original 3D-CBCT. The synthesized 4D images possess explicit patient motion while maintains the geometric accuracy of patient's anatomy at the time of treatment.

Results: We validated our model by comparing the synthesized 4D-CBCT against the 4D-CT dataset acquired in the same day from a protocol patient undergoing daily in-room CBCT setup and weekly 4D-CT for treatment evaluation. The correctness of contours and checkboard image fusion confirmed the accuracy of our model. In another patient example with large tumor shrinkage, we have observed excellent agreement of contours in different motion phases between the synthesized and acquired scans. Various imaging artifacts were greatly suppressed and soft-tissue visibility was drastically enhanced.

Conclusions: We have proposed and validated a novel framework to render high-quality daily 4D-CBCT.