Reconstruction and Enhancement of Four-dimensional Cone Beam CT using a Temporal Non-local Means Method

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Purpose/Objective(s): Four-dimensional cone beam computer tomography (4D-CBCT) provides respiratory phase resolved CBCT images in image guided radiation therapy. Conventionally, it is reconstructed by first dividing the X-ray projections into each respiratory phase according to a breathing signal and then reconstructing the image at each phase independently using the FDK algorithm. This usually leads to inadequate number of projections in each phase, resulting in low quality 4D-CBCT images with obvious streaking artifacts. The 4D-CBCT images are highly correlated along the temporal dimension due to patient's smooth respiratory motion pattern. Taking this temporal correlation into account can in principle facilitate the reconstruction. In this work, we propose a novel iterative 4D-CBCT reconstruction algorithm and an enhancement algorithm utilizing a tempoval nonlocal means (TNLM) method.

Materials/Methods: We define a TNLM energy term for a give set of 4D-CBCT images. Minimization of this term favors those 4D-CBCT images such that any anatomical features at one spatial point in one phase can be found in a nearby spatial point in neighboring phases. The 4D-CBCT reconstruction is achieved by minimizing a total energy containing the TNLM term. As for the image enhancement, 4D-CBCT images generated by the FDK algorithm are enhanced by minimizing the TNLM fiction while requiring that the solution is close to the FDK results. A forward-backward splitting algorithm and a Gauss-Jacobi iteration method are employed to solve the problems. The algorithms are implemented on GPU to achieve a high computational efficiency. Our algorithms have been tested on a digital NCAT phantom and a clinical patient case.

Results: The reconstruction algorithm and the enhancement algorithm generate visually similar 4D-CBCT images, both better than the FDK results. Quantitative evaluations indicate that, compared with the FDK results, our reconstruction method improves contrast-to-noise-ratio (CNR) by a factor of 2.56_3.13 and our enhancement method increases the CNR by 2.75_3.33 times. The enhancement method also removes over 80% of the streak artifacts from the FDK reconstruction results. The total computation time is _610 seconds for the reconstruction algorithm and _460 seconds for the enhancement algorithm on an NVIDIA Tesla C1060 GPU card.

Conclusions: By innovatively taking the temporal correlation among 4D-CBCT images into consideration, the proposed algorithms can produce high quality 4D-CBCT images with much less streak artifacts than the FDK results. Comparing the reconstruction and the enhancement algorithms, the resulted image qualities are similar. The shorter computation time makes the enhancement algorithm more attractive.