Design and Optimization of 3D VSHARP Scatter Correction for Industrial CBCT using the Linear Boltzmann Transport Equation

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We have developed VSHARP, a suite of scatter correction solutions that includes 2D VSHARP, a kernel-based correction, and 3D VSHARP, a correction based on a finite-element Linear Boltzmann Transport Equation (LBTE) solver. The LBTE solver gives similar results to Monte Carlo simulation, but in dramatically shorter time. In experiments, our 3D VSHARP simulated scatter fractions agreed with Monte Carlo results to 97% accuracy, yet ran over 5 million times faster. The 3D VSHARP correction relies on a first pass reconstruction, an object segmentation and material estimation, the LBTE solver, and several additional steps to rescale, interpolate, and subtract the scatter, all followed by a second-pass FDK reconstruction. Following our previous work, 3D VSHARP is now fully implemented in the Varex Cone Beam Computed Tomography (CBCT) Software Toolkit, called CST. All 3D VSHARP processing steps are implemented as modular plugins in a pipeline that can be integrated into OEM software or used standalone in our Workbench software, thus enabling the corrections to be used in conjunction either with the CST FDK reconstructor, or with an OEM's reconstructor. The algorithm run time can be affected heavily by parameter settings, especially the choice of sampling grid employed by the LBTE solver. To optimize the parameters, we have applied a genetic algorithm to find the Pareto front characterizing the tradeoff between speed and accuracy. Testing with 720 frames of 3720x3720 projection data to make a reconstruction volume of size 500x500x600, we found that excellent image quality can be obtained by using a coarse grid for a total of 20 seconds of LBTE computation time. We show the Pareto characterization, as well as demonstrations of 3D VSHARP image quality for industrial CBCT with significantly reduced scatter-induced artifacts such as streaking and shading.