Monte Carlo-free Deep Scatter Estimation (DSE) with a Linear Boltzmann Transport Solver for Image Guidance in Radiation Therapy

Fabian Jäger[1,2], Joscha Maier[1], Pascal Paysan[3], Michał Walczak[3], and Marc Kachelrieß[1,2]
[1]Division of X-Ray Imaging and Computed Tomography, German Cancer Research Center, Heidelberg, Germany
[2]Ruprecht-Karls-University Heidelberg, Heidelberg, Germany
[3]Varian Medical Systems Imaging Lab, GmbH, Baden-Dättwil, Switzerland

GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

Research for a Life without Cancer

Introduction

With cancer being one of the leading causes for death worldwide, the effort to extend and improve cancer treatment is significant. On-board CBCTs cannot yet be leveraged for treatment planning because of inferior image quality due to artifacts such as x-ray scatter or beam hardening. To address this issue, we recently proposed the deep scatter estimation (DSE) to predict high quality scatter estimates in projection domain [1, 5]. Here we demonstrate that DSE, when trained on LBTE scatter estimates, can achieve similar quality as Acuros and even outperform it in cases where the prior reconstructions are corrupted.

Material and Methods

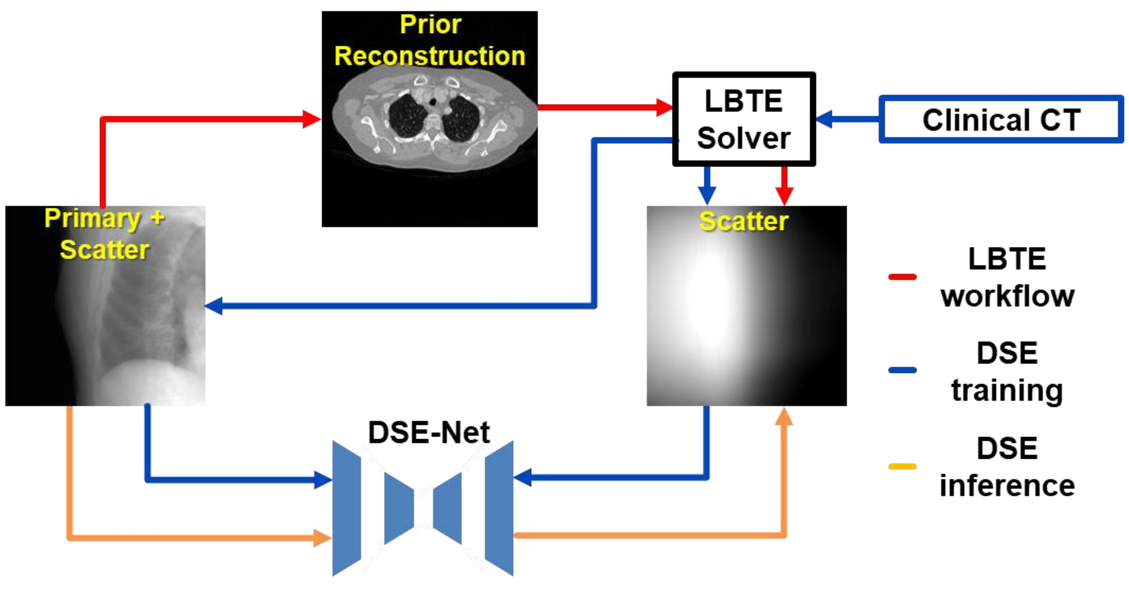

Figure 1: LBTE scatter corrections rely on a prior reconstruction (red workflow). DSE estimated the scatter in the projection domain (orange workflow) and is trained with labeled data generated by a LBTE solver from clinical CTs.

DSE [1] is a deep convolutional neural network based on the U-Net [4]. To generate labeled training data, scatter-corrupted projections (input) and the corresponding scatter distribution (label), 50 clinical CTs from a Siemens Somatom Force were used to simulate training and validation datasets (4:1 split) with Acuros® CTS [2]. The scanner geometry corresponds to the Ethos™ by Varian Medical Systems.

For testing, several patients from the validation set were fully simulated and a Multipurpose Chest Phantom N1 “LUNGMAN” by Kyoto Kagaku® was measured with different couch positions.

DSE-corrected reconstructions are compared to the ground truth, the scatter-free reconstruction of the simulated forward projection, and the different scatter correction methods applicable at the CBCT system, the LBTE solver Acuros and a kernel-based approach called fast adaptive scatter kernel superposition (fASKS) [3].

Method	Kernel	Acuros	DSE	Uncorrected
MAE	52.3 HU	11.1 HU	6.7 HU	104.3 HU

Table 1: Mean absolute error (MAE) at the patient between the reconstruction of the simulated ground truth and the scatter-corrected reconstruction as well as the uncorrected reconstruction.

Results and Discussion

Table 1 shows the results for the different scatter correction methods. As indicated above, the scatter correction with the LBTE solver relies on a prior reconstruction, which was corrected for scatter with fASKS for better initial image quality. On truncated scans as seen in figure 2 the deviation to the ground truth, the reconstruction of the scatter-free forward projections, for the DSE appears to be smaller than Acuros. As mentioned earlier, this is to be expected since LBTE methods rely on a first-pass reconstruction that is not completely artifact-free or even truncated. This leads to errors in the estimated scatter. For the measurements no scatter-free ground truth exists. A qualitative comparison of the different scatter corrections is shown in figure 3.

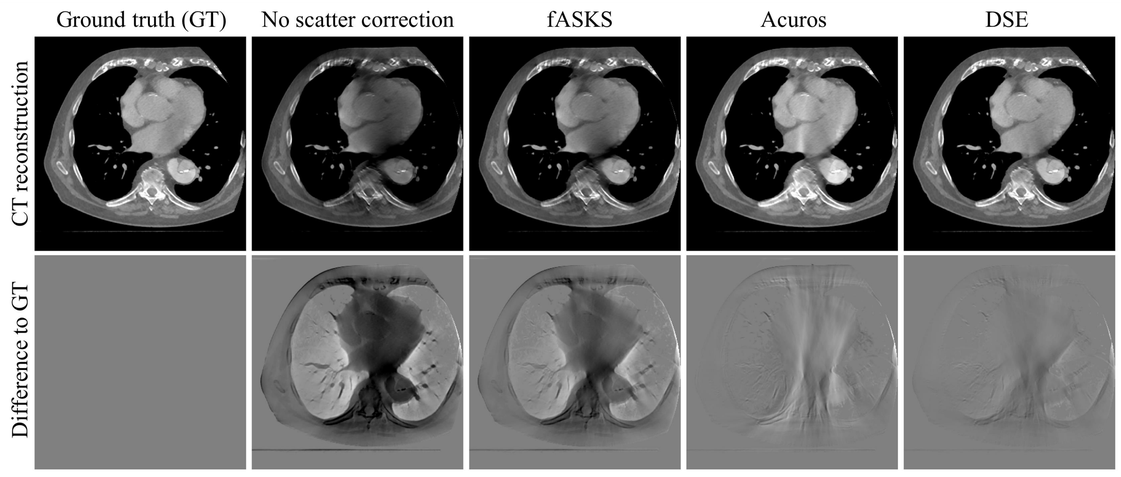

Figure 2: CT reconstructions of a simulated and truncated patient scan with and without scatter correction. The ground truth corresponds to the reconstruction of a scatter-free simulation. ***C* = 0 HU, *W* = 1000 HU**

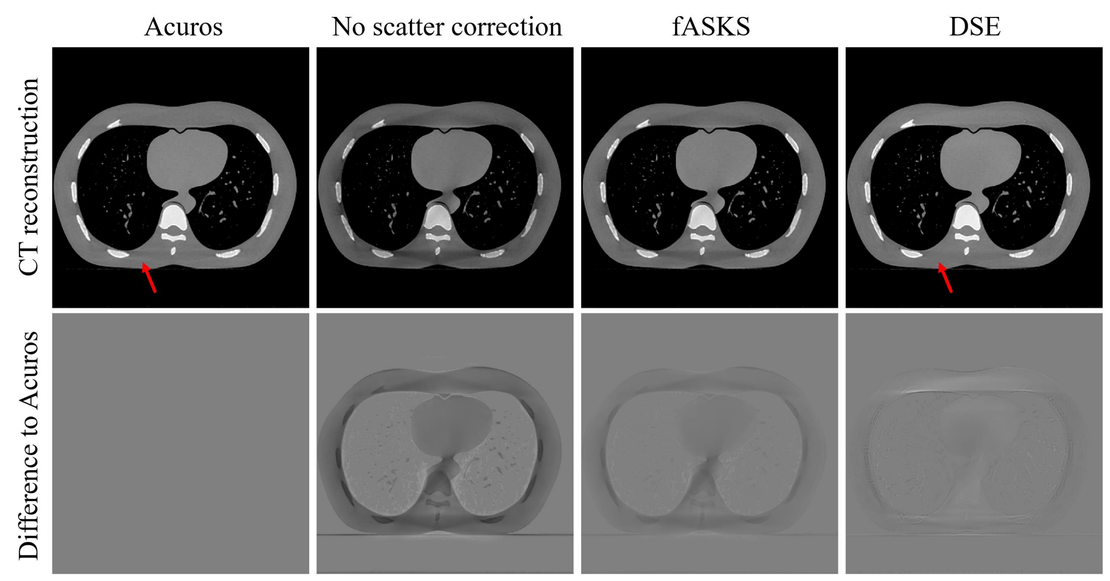

Figure 3: Reconstructed Lungman measurement at the Ethos with and without scatter corrections. The difference to Acuros is chosen, because it is the baseline scatter correction for the Ethos system. The red arrows show a dark streak which appears to be less pronounced in the DSE corrected reconstruction, compared to the other methods. ***C* = 0 HU, *W* = 1000 HU**

Conclusion

DSE can be trained on scatter estimates of a deterministic LBTE solver and shows good performance on real scans. Considering truncated simulations, Acuros introduced artifacts which are not visible in the DSE correction.

[1] Maier, Kachelrieß et al., *Journal of Nondestructive Evaluation* 37 (3 Sept. 2018), DOI: 10.1007/s10921-018-0507-z
[2] Maslowski and Wang et al., *Medical Physics 45* (5 May 2018), DOI: 10.1002/mp.12850
[3] Sun and Sar-Lack, *Physics in Medicine and Biology* 55 (22 Nov. 2010), DOI: 10.1088/0031-9155/55/22/007
[4] Ronneberger et al., *MICCAI (*2015), DOI: 10.1007/978-3-319-24574-4_28
[5] Maier, Kachelrieß et al., *Medical Physics 46* (1 Jan. 2019), DOI: 10.1002/mp.13274

Correspondence:
f.jaeger@dkfz-heidelberg.de