Influence of Data Completion on Scatter Artifact Correction for Truncated Cone-Beam CT Data

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Introduction

Severe cone-beam CT (CBCT) artifacts are caused by scatter and the interest to perform a good correction is very high. Scatter results in a loss of contrast, leads to cupping and streak artifacts and increases the noise level. In addition, the scatter-to-primary ratio increases as the distance between the rotation axis and the detector decreases, as it can be the case if a small field of measurement (FOM) is used to keep the patient dose low.

Materials and Methods

To reconstruct a volume with minimal artifacts, different artifact correction methods have to be taken into account. Here, the main focus lies on the scatter correction and the prearrangements needed to achieve a good basic volume for further artifact corrections.

Scatter Artifact Correction :

For the correction of x-ray scatter, a Monte Carlo based scatter simulation is used to simulate the physical path of photons through the object.[1] This is done based on an initial reconstruction or model of the scanned object. To estimate a reasonable Monte Carlo scatter distribution the prior volume has to match the real object as closely as possible. Both the attenuation value distribution inside the FOM and outside the FOM have to be accurate. The accuracy of the attenuation values outside the FOM strongly depends on the detruncation method used for data completion.

Truncation Correction:

If for example dental CT systems with a FOM diameter of 5 cm to 16 cm are used, as shown in Figure 1, the object does not completely fit in the FOM and truncation artifacts appear. In axial direction, this artifact appears as bright areas at the border of the FOM. Conventional detruncation algorithms are often used to compensate for this effect and lead to a good result inside the FOM.

Here, a cosine roll-off detruncation is used, where the rawdata are slowly faded out to zero following the cosine function. Standard detruncation algorithms are sufficient if one aims to perform an image reconstruction without truncation artifacts. But this is not the case if a scatter correction needs to be performed. To perform a good scatter correction it is essential to have a good knowledge about the gray value distribution outside the FOM. If the truncated part of the scan contains for example dense materials a simple detruncation algorithm does not take this into account, the result being an underestimation of scatter.

Here, we present the influence of different prior volumes used in a Monte Carlo simulation. The prior volumes differ in the detruncation algorithms used for data expansion, here we restrict ourselves to: no detruncation, constant detruncation, cosine roll-off detruncation and a prior-based detruncation[2] (Figure 3). For all detruncation methods, the data are expanded to twice their original size.

In case of the constant detruncation the basis values are continued constantly. For the cosine roll-off detruncation the basis values are slowly faded out to zero following the cosine function. Since the prior-based detruncation is based on prior knowledge, data from a different phantom are used for data completion. To do so, a simple

Materials and Methods

Patient Positioning:

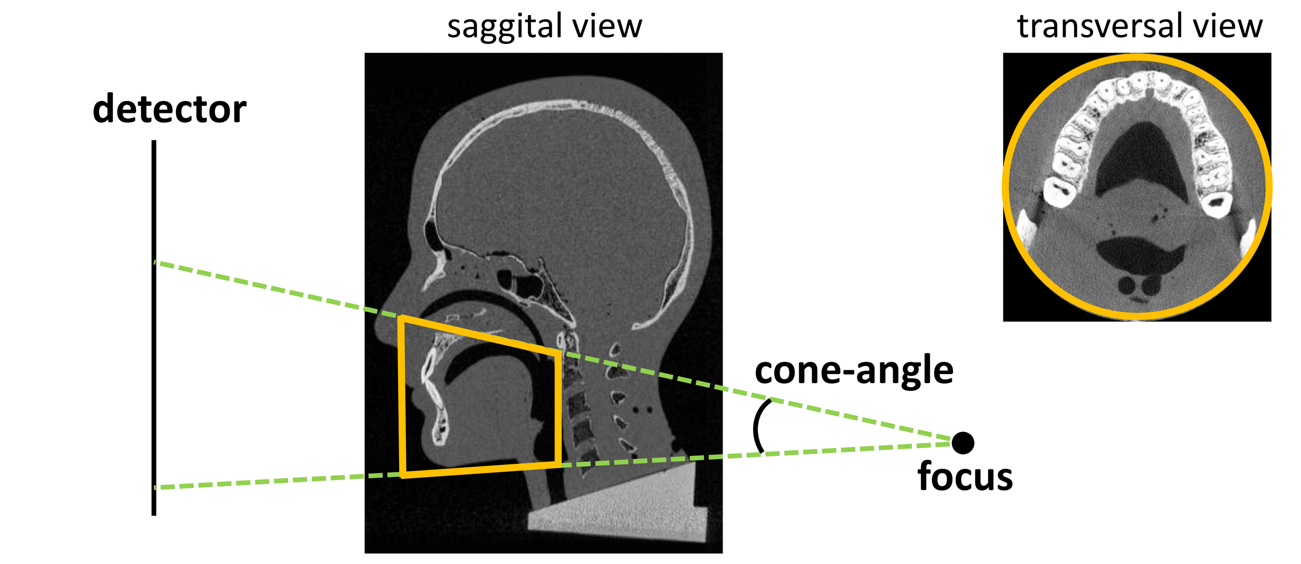

Figure 1: Patient positioning in a dental CT system. The green dashed lines symbolize the cone-angle, the orange box symbolizes the FOM in a dental CT.

Workflow:

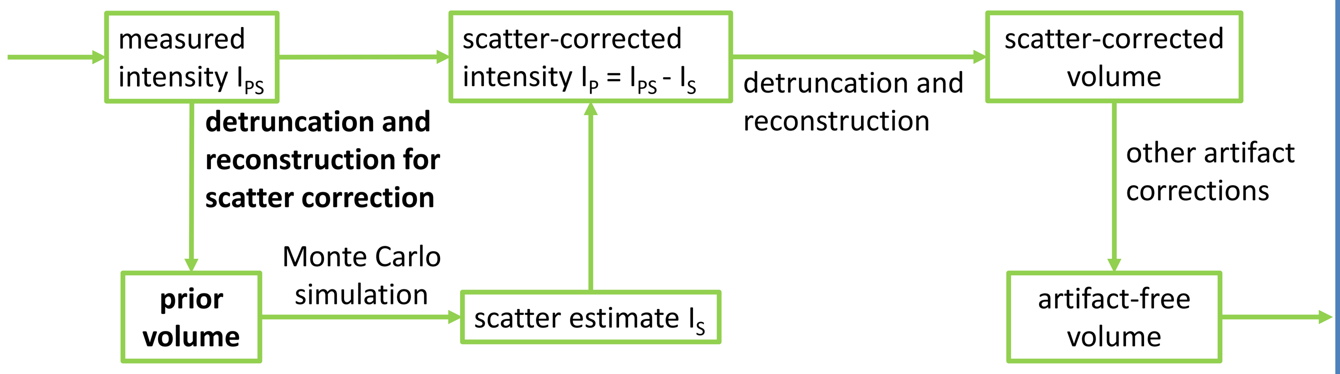

Figure 2: Workflow of the scatter artifact correction. Measured intensity I_{PS} = primary intensity I_P + scattered intensity I_S .

Detruncation:

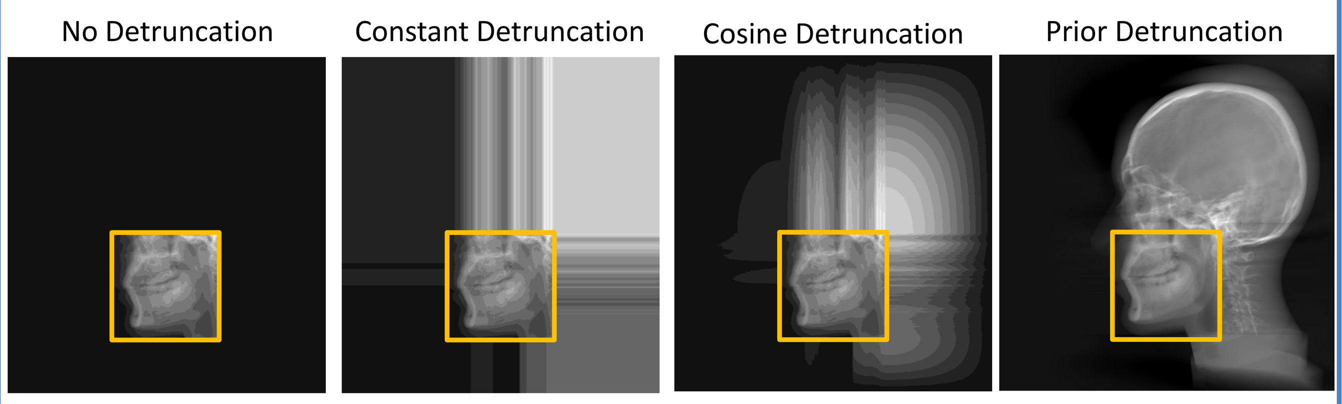

Figure 3: Projection data computed for no detruncation, constant detruncation, cosine roll-off detruncation, prior-based detruncation and the ground truth. The orange box corresponds to the FOM of a dental CT-system.

Results

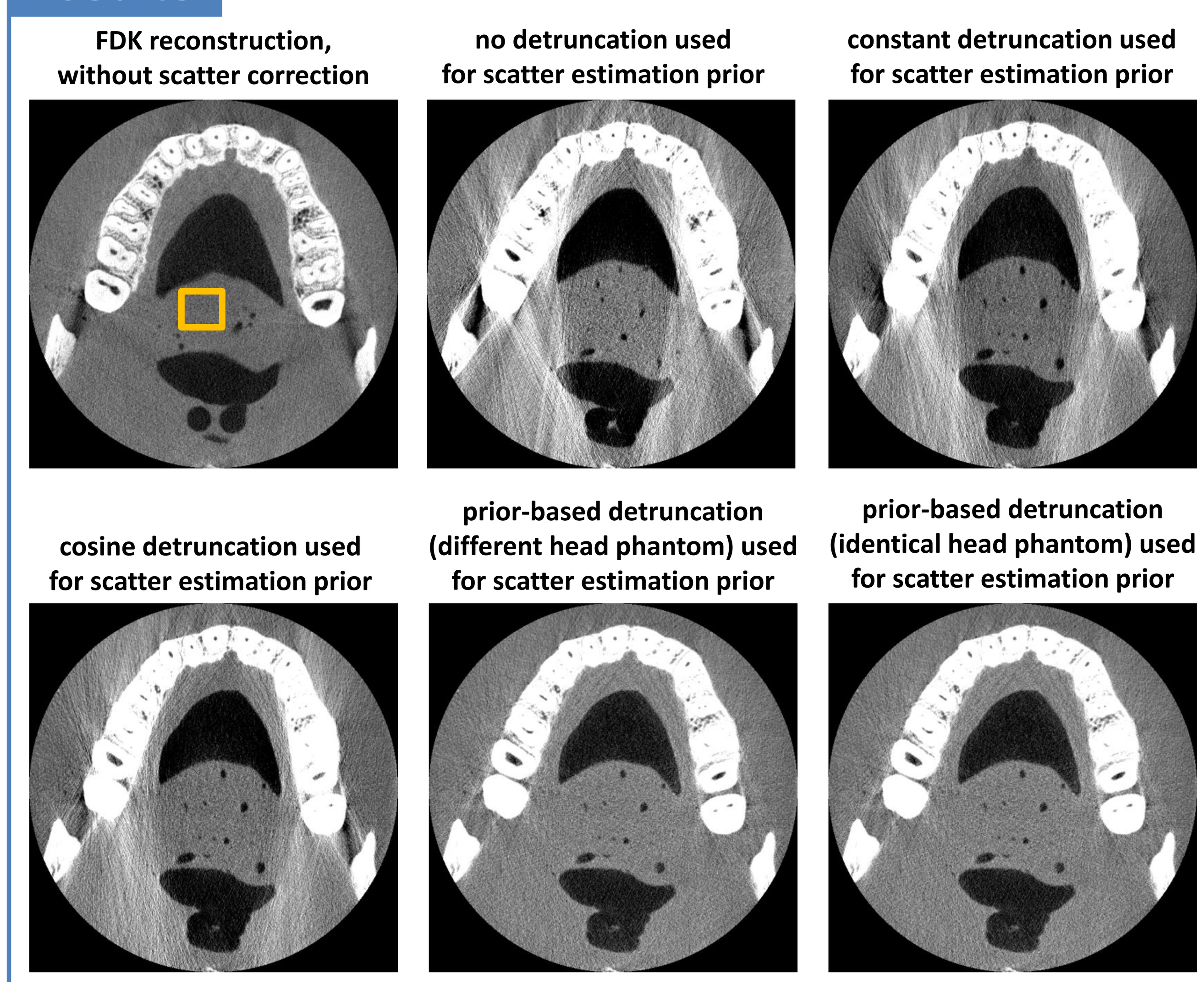

Figure 4: Scatter correction using different detruncation algorithms as scatter estimation prior. This volumes are additionally corrected for beam-hardening, cone-beam and truncation artifacts. C = 0 HU, W = 2000 HU.

Scatter estimation prior	CT-value after scatter correction	CT-value after scatter and beam-hardening correction
No Detruncation	-74 HU	-31 HU
Constant Detruncation	-172 HU	-139 HU
Cosine Detruncation	-113 HU	-76 HU
Prior Detruncation	-53 HU	-9 HU
Ground Truth	-42 HU	6 HU

Table 1: CT-values measured in the orange soft-tissue ROI shown in Figure 4. The ground truth corresponds to the reconstruction using the original phantom to perform a prior detruncation.

registration of the dataset to the truncated CBCT volumes is done, followed by a forward projection of the registered volume into the CBCT geometry and used for data extrapolation.

Additionally the data are compared to the case where the prior volume for the scatter correction is not detruncated.

Other Artifact Corrections:

As a water precorrection, necessary to achieve accurate CT-values inside the FOM, an empirical cupping correction (ECC)[3] is chosen to linearize the attenuation values using a precorrection function of polynomial form. For the beam-hardening correction, the analytical beam-hardening correction (ABHC)[4] is used. This correction seeks to iteratively find a beam-hardening corrected volume g whose polychromatic forward projection X_g yields the required rawdata. If only one iteration is considered this results in the following update equation: $g^{(1)} = f + X^1(X_f - X_g)f^{(1)}$ where f is the initial volume, X^1 a filtered backprojection and X_f a monochromatic forward projection.

The cone-beam artifacts are corrected using a two pass cone-beam artifact correction. [5]

Results

The reconstructed volumes using different detruncation methods for the scatter correction are shown in Figure 4. The corresponding CT-values for soft tissue measured in the yellow box in the volumes of Figure 4 are listed in Table 1, where the ground truth corresponds to the prior-based detruncation where the identical head phantom was used for data completion. As a reference, the same phantom was measured in a clinical CT (Definition Flash, Siemens Healthineers, Forchheim, Germany, tube voltage 140 kV, head protocol) and the CT-value of soft tissue in the same ROI was measured to be 4 HU. In case of a simple FDK reconstruction a CT-value of -181 HU was measured in the same ROI. In case of a scatter estimation prior based on the constant detruncation, the cosine detruncation or no detruncation bright streak artifact are present in the reconstructed volume leading to incorrect CT-values and an inhomogeneous CT-value distribution well visible in the soft tissue areas. A nearly artifact free volume can be reconstructed if the scatter estimation prior is based on the prior detruncation. If the scatter estimation prior is based on the prior detruncation a CT-value accuracy of 15 HU can be achieved, compared to the ground truth value. The other scatter estimation priors lead to a worse CT-value accuracy. This means that in addition to the best visual quality the result of the prior-based detruncation for scatter estimation leads by far to the most accurate CT-values in soft tissue.

To perform a solid and robust scatter correction, the detruncation used for the scatter estimation is of high importance. Based on an accurate scatter correction the subsequent CBCT artifact corrections leads to nearly artifact free images.

Acknowledgements

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