Scattering Correction in Cone Beam Computed Tomography

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Abstract
Quantitative reconstruction values in Cone Beam Computed Tomography (CBCT) are often miscalculated due to the presence of secondary radiation originating from scattering of photons inside the object and detector under consideration. The effect becomes more prominent and challenging in case of high X ray source energy (of a few 100 keV) which is used in industrial Non Destructive Testing (NDT), due to higher scatter to primary ratio (SPR).
This paper describes a scatter correction algorithm for correcting the combined scattering due to the object and the detector based on Scatter Kernel Superposition (SKS). Scatter correction is performed for projections obtained with 400 kV X ray source, using pencil beam kernels which are simulated in RT module of the software CIVA for NDT simulations. Two methods for scatter correction using SKS approach are discussed in the paper. In the first method, we use a discrete approach in which kernels for only few thicknesses are simulated for scatter correction. In the second method a continuous approach is used where the kernels are also interpolated from the discrete kernels for other thicknesses. The two methods of scatter correction are performed on the projections of an iron hub and they are compared. The obtained results prove that the continuous method produces better edge enhanced corrected projections and the method results in improved reconstruction values.

1 Introduction
Quantitative reconstruction values in CBCT are miscalculated due to presence of secondary radiation originating from scattering of photons inside the object under consideration and the imaging detector leading to cupping and streaking artifacts [1]. The effect is prominent in the NDT energy range (a few 100 keV) due to higher SPR.

There are various existing CBCT scatter correction methods which can be summed up mainly into two categories: Pre-processing methods such as anti-scatter grids [2] and air gap method [3] which are able to separate the scatter from the primary photons based on the difference of their incidence angles, and Post-processing methods such as beam stop array [4] and Scatter Kernel Superposition (SKS) [5] which estimate the scatter signal from the scatter-contaminated projection using some prior knowledge of the scatter distribution.

This paper focuses on the scatter correction using SKS deconvolution method for industrial energy range used in the NDT of materials and components, where the SPR is expected to be very high.

2 Context : Methods and Materials
SKS deconvolution method corrects scatter per projection by convolution of the measured signal with the pencil beam kernels $h_T$ using equation 1, simulated by varying thickness of the slabs
of same material as the object in CIVA [6] RT module developed for NDT simulations by CEA. The weight of the kernel is the ratio of scatter at each pixel of the detector to the primary at the pencil beam centered pixel. The kernels obtained are fitted to equation 3 [5] formed with amplitude factor $C(k, l)$ given by equation 4 and form function $G(m - k, n - l)$ given by equation 5 made of two symmetric gaussian functions.

$$S(m, n) = \sum_k \sum_l P(k, l) h_T(k, l)(m - k, n - l)$$  \hspace{1cm} (1)

where,

$$T(k, l) \approx \frac{1}{\mu} \ln \frac{O(k, l)}{P(k, l)}$$ \hspace{1cm} (2)

$$h_T(m - k, n - l) = C(k, l) \cdot G(m - k, n - l)$$ \hspace{1cm} (3)

$$C(k, l) = A \cdot \left( \frac{P(k, l)}{O(k, l)} \right)^{\alpha} \ln \left( \frac{O(k, l)}{P(k, l)} \right)^{\beta}$$ \hspace{1cm} (4)

$$G(m - k, n - l) = \exp \left( -\frac{(m - k)^2 + (n - l)^2}{2\sigma_1^2} \right) + B \exp \left( -\frac{(m - k)^2 + (n - l)^2}{2\sigma_2^2} \right)$$ \hspace{1cm} (5)

Only a few thickness kernels are simulated, for the rest of the kernels parameters $\alpha, \beta, A, B, \sigma_1, \sigma_2$ are interpolated in order to evaluate the advantage of continuous kernels approach.

Acquisitions are performed on an iron hub of height 32 mm and external diameter 52 mm as shown in Figure 1. X-ray spectrum of maximum voltage 400 kV with 4 mm of Pb + 1 mm of Cd filter is used with Thales Flashscan 33 detector [4]. The corrected projections are reconstructed using FDK algorithm in CIVA.

Figure 1: Picture of sample of the iron hub [4]
Two scatter correction approaches were used. In the discrete kernels approach, one average value of parameters $\alpha, \beta, A, B, \sigma_1, \sigma_2$ for three thickness ranges 0-10 mm, 10-20 mm, 20 mm and above was calculated. In the continuous kernels approach, the parameters were also interpolated with respect to thickness. Figure 2 shows the 1D profile of the MC simulated kernels for different thicknesses.

![Plot profile of the simulated kernels using MC simulation in CIVA](image)

The obtained results are discussed in the next section.

3 Results and Discussion

Figure 3 displays a sample projection. To evaluate the performance of continuous and discrete scatter correction on the projections, the vertical and horizontal profiles of the corrected and uncorrected normalized projections are plotted in Figure 4. Figure 4 also displays calculated scatter profiles with discrete and continuous approach.

It is evident from the vertical profile of the corrected projection that continuous method performs better edge enhancement of the object as compared to discrete method. This is due to better sampling of the kernels with respect to thickness at the edges.

Figure 5 displays reconstruction slices of the top tip of the iron hub obtained for uncorrected and corrected projections using continuous and discrete method. In the considered energy range the value of linear attenuation constant per cm for mean energy 320 keV is 0.83 which is in agreement with the obtained result. Continuous method presents improved reconstruction values than the discrete approach in the top tip reconstruction slice as can be seen in Figure 6 due to better edge enhance by the continuous approach.

The obtained result of the scatter profile and reconstruction values is in agreement with with correction performed using beam stop arrays method by A. Peterzol [4] which requires many
Figure 3: Sample projection of iron hub sample

Figure 4: a) Horizontal profile b) Vertical profile of uncorrected and corrected projection by continuous and discrete method

Figure 5: Reconstruction slice of a) Uncorrected projections b) Corrected projections by discrete method c) Corrected projections by continuous method

acquisitions for the correction leading to higher dose.
Figure 6: Plot profile of the reconstruction slice of a) Uncorrected projections b) Corrected projections by discrete method c) Corrected projections by continuous method

4 Conclusion and Perspectives

Scatter Correction using pencil beam kernels produces significant improvement in the quantitative reconstruction values for the iron hub. The continuous approach offers superior improvement in the edges of the object after correction due to extended number of kernels. The outcome of the reconstruction values is also improved in continuous approach than the discrete approach especially for the reconstruction slices of the tips of the iron hub.

The obtained results are in agreement with another scatter correction method based beam stop array for the same acquisition data. Beam stop array method requires at least two scans: one for obtaining scatter behind the beam stop arrays and one for the signal without beam stop arrays. Moreover, the imaging geometry changes with the insertion of the beam stops and the measured scatter signals do not match those without the beam stop arrays. To correct for this, a series of measurements using beam stop arrays with different sizes are needed to be carried out. This increase in the extra number of measurement causes increased X-ray exposure. It also prolongs the scanning time. Finally, this method is also subject to error due to object motion.

Scatter correction with SKS method is practical as it does not require additional hardware. It has easy implementation and is not subject to motion of the object as the correction is performed after the projections are generated. No additional scanning time is required. It is also computationally efficient as only a single scan is required leading to no further increase in the dose.

The efficiency of the continuous approach for medical energy and MeV range is under investigation. It is also interesting to investigate the performance of the method for heterogeneous objects made of two or three material.
References


