A scattering reduction method for X-ray spectral computed tomography

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Summary: Spectral X-ray computed tomography is a technique allowing energy resolved acquisitions. Scattering contribution to the primary beam is one of the major source of artifacts in the reconstruction (e.g. streaking, cupping, loss of contrast). In this work, we carry out experiments to separate the spectral distribution of the scattered radiation component. The findings are validated by Monte Carlo simulations.

1. INTRODUCTION

In the last century, there has been a large scientific and industrial interest in the improvement of X-ray Computed Tomography (CT) involving X-ray tube sources, and its applications are found in a wide range of fields (e.g. medical imaging, non-destructive testing, geoscience, etc.). Most of the techniques applied involve simple reconstruction methods such as the Filter-Back-Projection (FBP) and energy-integrating detectors. Assuming ideal detectors, there are mainly two physical aspects deteriorating the quality of the image, beam hardening and X-ray scattering. Both of them lead to severe streaking and cupping artifacts and the latter additionally to a significant loss of contrast in the image. To overcome these limitations, a new method is currently being developed, namely Spectral X-ray CT, which involves novel energy-discriminating photon-counting detectors to allow having energy resolved spectra of the measured observables. Several experiments have shown how this technique, with proper calibration, can minimize beam-hardening effects without any need of computational corrections. Recent studies explored the impact of scatter radiation in spectral CT [1], which resulted to be of greater importance at low energy values, where the photoelectric absorption events are dominant (i.e. below 50 keV). However, developing an efficient correction technique has proven not to be a trivial task. We employ an experimental setup to predict the spectral distribution of the scattering component, and use that information to reduce its contribution to the total attenuation.

2. BACKGROUND THEORY

In X-ray CT experiments with a fan-beam geometry and assuming ideal detectors (i.e. neglecting pile-up effects, charge sharing, etc.), we can principally express the measured intensity $I(E,p)$, function of energy E and pixel p as:

$$I(E,p) = P(E,p) + S(E,p) \tag{1}$$

where $P(E,p)$ is the primary radiation and $S(E,p)$ is the scattered radiation. In presence of a sample, the latter term can be split up in two components:

$$S(E,p) = S_{obj}(E,p) + S_{env}(E,p)$$

with S_{obj} representing the scattered radiation incoming from the sample and S_{obj} the scatter contribution from the environment (e.g. reflections, scattering originating from air, etc.). Therefore, whenever it is possible to obtain a measurement setup in which the scatter component can be neglected, it is also feasible to separate its component.

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3. EXPERIMENTAL METHOD

The experiments were carried out using a custom X-ray CT scanner at DTU Physics, in Kongens Lyngby (Denmark). The sample, chosen to expose the issue of accurately discriminating organic materials of similar total attenuation coefficients, is composed of an aluminium rod and four glass vials containing different compounds: H_2O, H_2O_2, powder sugar and a powder penthrite (PETN) simulant, mounted on a rotating support. We performed a single slice tomography scan of 37 projections with a fan-beam geometry. The detector used (Multix ME-100) is a linear array of pixels of size 50 mm, able to separate photons in $n = 1, 2, ..., 128$ energy bins E_n linearly distributed between 20 and 160 keV. We design two experimental setups to separate the scattering component. In the first acquisition, namely "Setup 1" the fan-beam was collimated using a set of slits to cut the vertical opening of the X-ray beam, in the second acquisition, "Setup 2", an additional set of slits was introduced before the detector to suppress the scattered radiation, i.e. the $S(E, p)$ term of eq. (1). We then used an iterative reconstruction algorithm, based on the minimization of the image total variation (TV) [2], to address the few-projections limitation. In order to validate our findings, simulations were performed as well using McXtrace [3], a Monte Carlo software package for simulating X-rays.

4. RESULTS

The results of the experiments are displayed in Fig. 1, showing firstly the slice reconstruction of the sample from the data set acquired with Setup 2 (a), and secondly the scattered component (b). The latter was obtained by subtracting the reconstruction of Setup 1 from the former. The scatter component is thus found from the decrease in attenuation coefficient that stems from scattered photons being detected in the uncollimated detector. The distribution of the scattered intensity corresponds week to the solid materials which has the highest scattering cross section. In this example, we show the results for a single energy channel. It was also observed a greater impact of the scatter component at low energies, whereas it decreases dramatically as the Compton region is approached (above 50 keV). We found a good match between simulations and experiments, which supports the potential use as corrective method.

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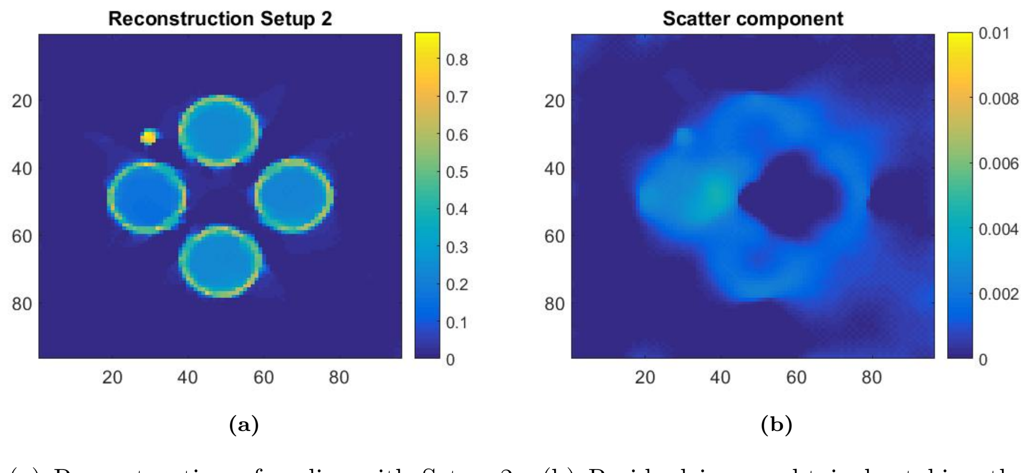

Figure 1: (a) Reconstruction of a slice with Setup 2. (b) Residual image obtain by taking the difference between the reconstruction of acquisition of setup 2 and 1. It can be seen that the scatter component is of major relevance for powder compounds (i.e. sugar, left, and PETN, bottom) and the aluminium, top-left.