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Exploiting the MEDIPIX2 detector for the reconstruction of X-ray spectra

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ABSTRACT

The single photon counting pixel detector MEDIPIX2 has been used in a variety of applications. Because of its spectral capability, the detector can be used as spectrometer. However, the measured spectrum is not the real incident spectrum as the MEDIPIX2 suffers from charge sharing because of its small pixel size.This implies that the energy information is smeared out heavily. Taking the measured spectrum and the responses to monoenergetic exposure we applied some deconvolution methods to determine the incoming spectrum.

1. Introduction

X-ray tubes are used as radiation source in a variety of applications. Therefore, the knowledge of the X-ray spectrum is an important task for example in case of medical application. With an energy sensitive detector such as the MEDIPIX2 [1] detector it is possible to measure such a spectrum. With its adjustable energy thresholds one is able to have information about the energy of every single photon that interact within the detector. But because of its small pixel size and other physical effects such as the diffusion of charge carriers created in the sensor material, this detector suffers from charge sharing. This implies that an incoming photon may be registered by more than one pixel. Considering further the energy dependent absorption efficiency it becomes obvious that the measured energy deposition spectrum differs considerably from the incoming X-ray spectrum. The aim of this paper is to show that one can reconstruct the incident X-ray spectrum using the MEDIPIX2. Results of the reconstruction using simulated and measured data will be presented and discussed.

2. Basics and methods of spectrum reconstruction

The Detector response $M(E')$ to an incident spectrum $S(E)$ can be written as

$$M(E') = \int_0^\infty D(E',E)S(E)\,\mathrm{d}E$$

where E is the primary photon energy, E' the energy deposition in the detector and $D(E',E)$ is the normalised detector response function to monoenergetic exposure of energy E. The knowledge of the responses to monoenergetic input is fundamental to reconstruct a polychromatic spectrum. Because of the lack of monoenergetic sources in real-world environments, only few monoenergetic responses were measured, while a large number of monoenergetic responses have been simulated using our Monte Carlo tool ROSI [2]. The simulated and measured responses were in good agreement [3]. This confirms the fact that the modelling of the energy responses was correctly done. We can then rely on these responses to determine the incoming spectrum.

For a known response function D the measured spectrum M can be deconvoluted to obtain the incident spectrum S. We define energy bins ΔE of a width of about 1–10 keV. The conversion of the integral equation to a set of linear equations can be written in matrix notation as follows:

$$M_i = \sum_{j=1}^{\max} D_{i,j}S_j.$$

In this equation the energy deposition is indexed with i and the incident photon energy with j. In our case these channels (energy bins) are of the same size. The equation was solved using two methods: The spectrum stripping and matrix inversion.

The spectrum stripping is based on the successive subtraction of the response function to monoenergetic input from the actually measured spectrum. Let us assume we have N energy channels for the reconstruction. We start at the highest energy bin. This is usually the one corresponding to the highest energy deposition bin with a non-zero counter and is indexed N. The input intensity for this bin is then: $S_N = M_N/D_{N,N}$.

We then multiply the response $D_{i,N}$ with S_N and subtract it accordingly from the deposition spectrum M to reduce the contribution of this bin to zero. The remaining spectrum can be considered as the energy deposition spectrum without the contributions of the highest energy bin. This remaining deposition spectrum is used as input deposition spectrum in the following

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step. This method is repeated until the lowest energy bin is reached. For properly normalised response spectra, the factors S are the reconstructed intensity of the incident spectrum.

Matrix inversion was the second method we used to reconstruct the incident spectrum. In order to obtain numerically stable results with this method, the energy bin width for reconstruction has proven to be greater than 1.5 keV. This is related to the requirement of linearly independent response functions. Based on the maximum likehood principle and using a matrix notation, the searched spectrum is given by

$$\mathbf{S} = (D^T D)^{-1} D^T \mathbf{M}.$$

3. Results of the reconstruction

3.1. Simulations

All our simulations were performed using our Monte Carlo tool ROSI [2]. The response functions to monoenergetic exposure were simulated with 10 millions of photons. For testing our methods with simulated spectra we used as set-up a pyramidal X-ray source and the MEDIPIX2 (implemented with all its components). The incident spectra had 100 millions of photons. These spectra have been measured and published by Dierker et al. [4] and used as input to our simulations. Figs. 1 and 2 show in comparison the reconstructed and incident spectra of a tungsten tube at 40 and 80 kV. As we can see the incident and reconstructed spectra are in good agreement qualitatively but also quantitatively. For energy bins below 1.5 keV the reconstructed spectrum using stripping is closer to the incident spectrum Fig. 1. This is expected because the response functions are nearly dependent for small binning, so the matrix inversion becomes inaccurate.

For higher acceleration voltage the reconstruction is overall successful (see Fig. 3). But the reconstructed and incident spectra are not in very good agreement for energies >80 keV. The reason is that we have very poor statistics due to the bad efficiency of the silicon detector at those energies.

Both reconstruction algorithms deliver quite similar results and deviate only for small energy binning, see Fig. 4.

3.2. Measurements

As radiation source we operated a Siemens Megalix Cat radiator at a tube current of 10–35 mA and positioned the MEDIPIX2 in the primary photon field at a distance of 1 m resulting in a count rate of about 100 MHz on the MEDIPIX2 for the lowest energy threshold. We then performed a threshold scan with energy steps of 2 keV.

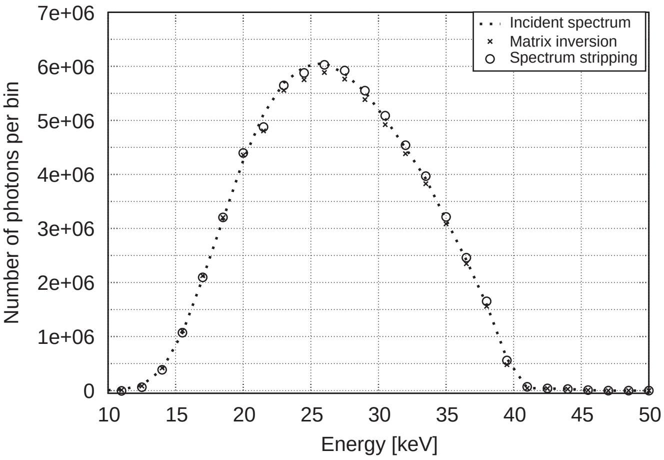

Fig. 1. Reconstruction of a simulated 40 kV incident tungsten spectrum. The two reconstruction methods give almost identical results.

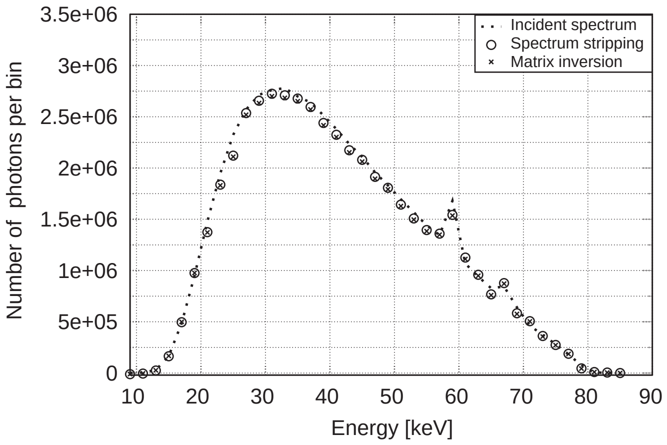

Fig. 2. Reconstruction of a simulated 80 kV incident tungsten spectrum. The two reconstruction methods give almost identical results. The K-α and K-β fluorescence lines of tungsten are clearly visible.

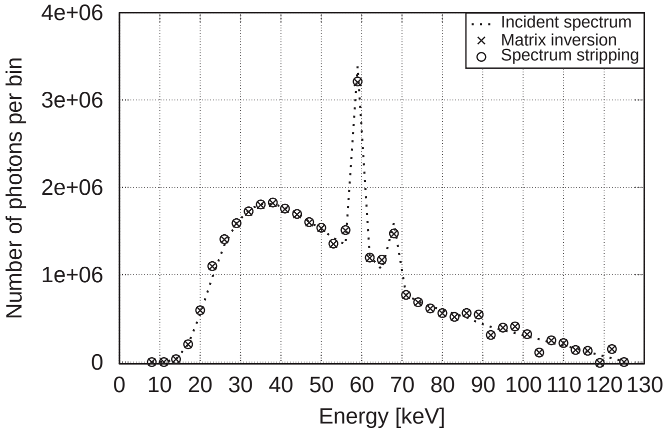

Fig. 3. Reconstruction of a simulated 125 kV incident tungsten spectrum. The two reconstruction methods give almost identical results. The K-α and K-β fluorescence lines of tungsten are clearly visible.

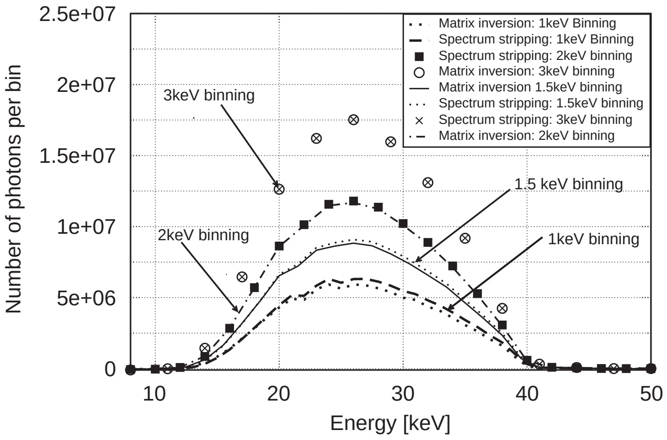

Fig. 4. Comparison of the reconstruction algorithms. For an energy bin width below 1.5 keV the results are a bit different.