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P2.27: A simulation study of instant-retrigger technology for pulse pileup correction in clinical photon-counting tomography

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Photon-counting technology matured enough to be implemented in clinical computed tomography (CT) scanners with the potential to revolutionize clinical practice due to low imaging noise, uniform spectral weighting, and inherent spectral separation. Photon fluxes in clinical CT can reach up to 10^8 counts $\mathrm{mm}^{-2}\mathrm{s}^{-1}$, imposing significant technical challenges on the counting speed of photon-counting detectors [1]. Pulse pileup is the effect in which two or more photons impinging the same detector pixel are processed as a single event, leading to counting loss and spectral distortion of the signal. In clinical CT, the conditions for pulse pileup to occur are usually met at high tube currents and can be observed inside the lungs or at the edges of the patient's body. Spectral distortions also have a significant impact on quantitative imaging tasks such as iodine quantification and virtual monochromatic imaging. An effect occurring independently of photon flux is charge sharing due to fluorescence effects and the spreading of a charge cloud, causing multiple counts at lower energies and blurring of the image. Pulse pileup and charge sharing contradict each other to some extent because i) larger pixel sizes reduce charge sharing between pixels while increasing the probability for pulse pileup and ii) faster ASIC helps distinguish single photons in high-flux conditions while reasonably slower detectors allow for integration of split charges created due to the charge sharing. Thus, hardware-based methods are often implemented to correct for one or both effects depending on the detector design and intended application.

In this work, we investigated the potential of instant-retrigger technology developed by DECTRIS Ltd. to improve non-paralyzable detectors in high-flux conditions [2]. Instant retrigger technology re-evaluates the pulse signal after a predetermined deadtime interval after each count and potentially retriggers the counting circuit in case of pulse pileup. The respective deadtime interval is adjustable and accounts for the width of a single photon pulse. The instant-retrigger analytical model was developed and implemented inside the DukeSim CT simulator to generate realistic CT simulations of the XCAT chest [3] phantom containing iodine contrast. DukeSim contains primary ray-tracing and Monte Carlo scattering models, realistic models of CT geometries, and a model of a photon-counting detector including charge sharing model and paralyzable and non-paralyzable detector configurations [4]. For this work, we used a 1.6 mm thick CdTe sensor bulk and 0.5x0.5 mm detector pixel size. The instant-retrigger analytical model [5] was applied after charge sharing and compared against the other two models for the task of material decomposition. Material decomposition is described as:

$\mu(E) = \mu_1(E)\, x_1 + \mu_2(E)\, x_2$

where $\mu_1(E)$ and $\mu_2(E)$ are known linear attenuation coefficients of basis materials (e.g., soft tissue and bone), x_1 and x_2 are energy-independent coefficients (in 2D called basis images/maps), and $\mu(E)$ is the measured value for each voxel. The basis images, which represent the equivalent concentrations of basis materials for each voxel, encode the quantitative information about the voxel composition. Figure 1 shows how the retriggering mechanism improves spectral information in high flux conditions in comparison with slightly slower non-paralyzable and paralyzable detectors. Figure 2 shows decomposed soft tissue and bone maps of the virtual XCAT phantom obtained using the simulation without modeling the pulse pileup effect. Figure 3 shows how the accuracy of material decomposition depends on the retrigger time.

Faster retriggering time improves spectral response and maintains accurate material decomposition in spectral CT. Although retriggering times of 15 ns are achievable with current detectors, more accurate analytical models accounting for variable pulse lengths generated by polychromatic sources might be needed to determine optimal values.

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