Look-up Table-Based Simulation of Scintillation Detectors in Computed Tomography

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Introduction

- Scintillation detectors are the current state of the art technology for CT systems
- CT detectors are constantly improved in terms of coverage, resolution and signal quality
- **Purpose:** Designing a new CT detector requires precise knowledge on its detection properties. Evaluating these mostly relies on simulation data, as building prototypes is very expensive
- **Problem:** Full scale Monte-Carlo simulations of particle interactions within the detector are very time consuming: Simulating the measurement process of a CT scan is not feasible on current computers
- **Solution:** Look-up table (LUT) based simulation of the measurement process from the detection of incoming X-ray photons to the electronic output signal of the detector. It is **capable of simulating whole CT scans within hours** at almost the same precision as a full-scale particle interaction simulation

Detector Layout

Figure 1 shows the basic layout of a CT scintillation detector:

- The scintillator material converts X-rays into optical photons
- The reflector and the septa prevent optical photons from reaching other detector pixels or leaving the detector

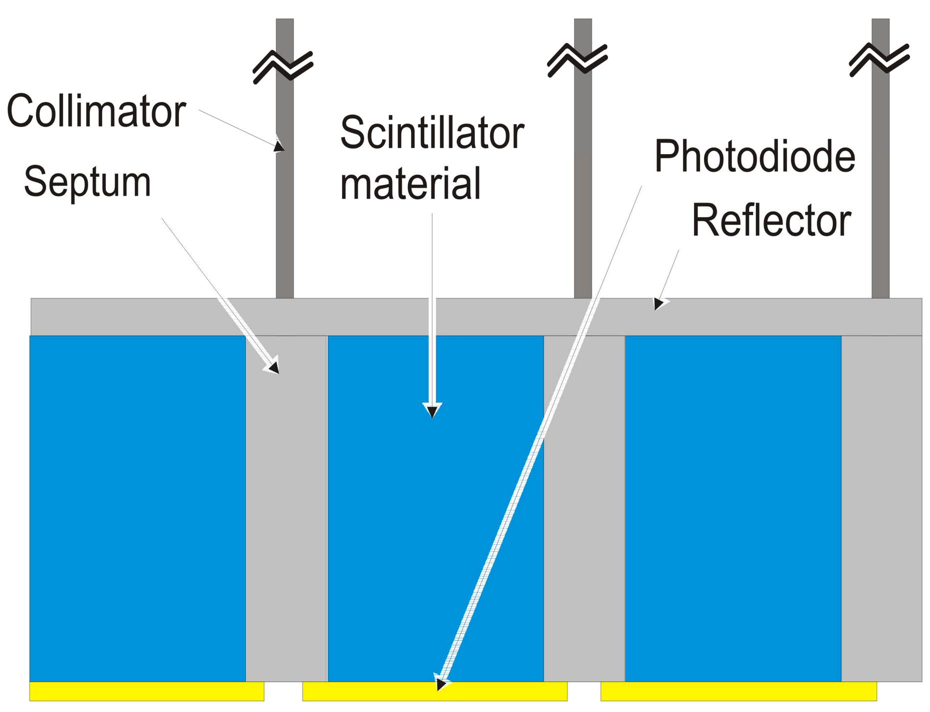

Fig.1: Basic scintillator layout

- The photo diode converts optical photons into an electrical signal

Simulation

Simulated effects that influence the detector performance:

- X-ray photon detection probability depends on photon energy, scintillator material and pixel geometry
- X-ray interactions deflect or create X-ray photons on different paths that may interact within other pixels (*X-ray cross talk*)
- Depending on their original position, optical photons may penetrate septa and reach other pixels or get lost (*optical cross-talk*)
- Detection of optical photons may be delayed (*afterglow*)

- Two pre-computed LUTs are needed for each detector geometry:
  - energy dependent X-ray photon interaction data [1]
  - position dependent detection probability distributions of optical photons (see Fig. 3, [2])

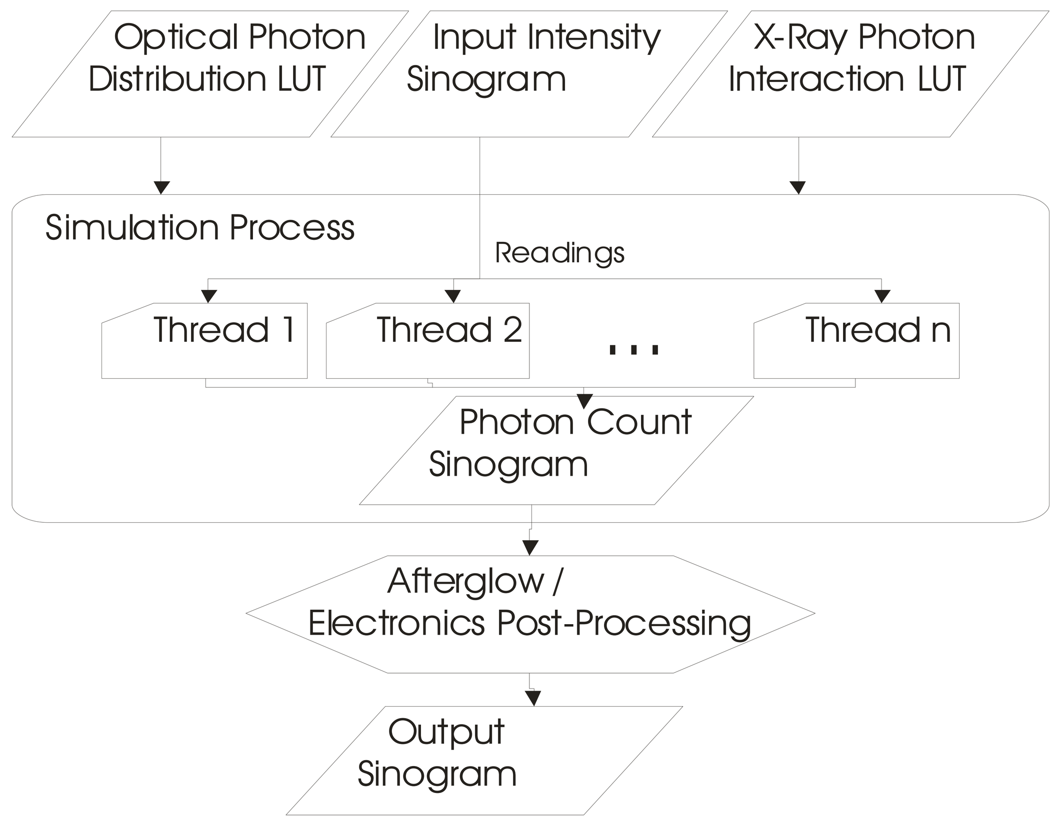

Fig. 2: Simulation workflow

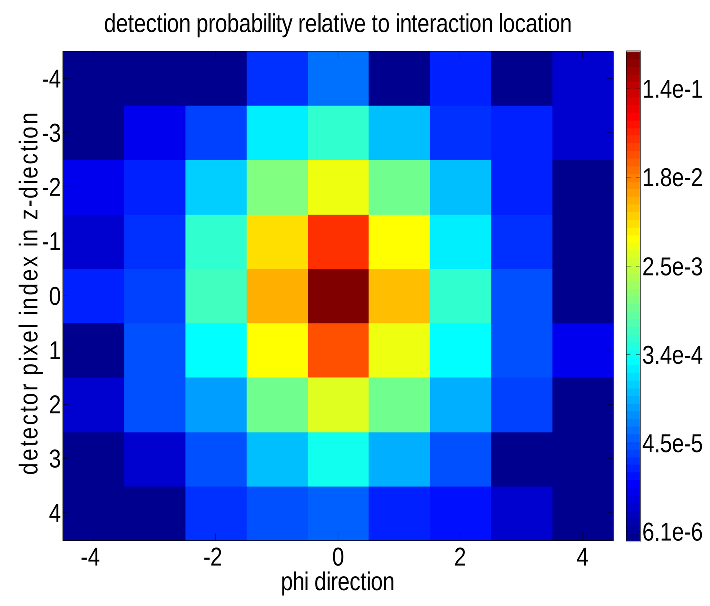

Fig 3: Optical photon distribution example

- Interaction locations within detector pixels are discretized so X-ray interaction and optical photon transport can be separated
- Input data consists of incident photon spectra for each pixel
- Afterglow and electronics effects can be handled by post-processing the computed photon count signal.

Results

- **Comparison**: 2D noise power spectrum (NPS) of proposed simulation and fully single-X-ray-photon based Monte-Carlo simulation (see Fig. 4)
- Simulated response of a 512x512 pixel Gd_2O_2S detector to a low-flux flat-field (Kerma 1.58e-5 Gy)
- Mean deviation on whole 16x16-NPS: 3.04%

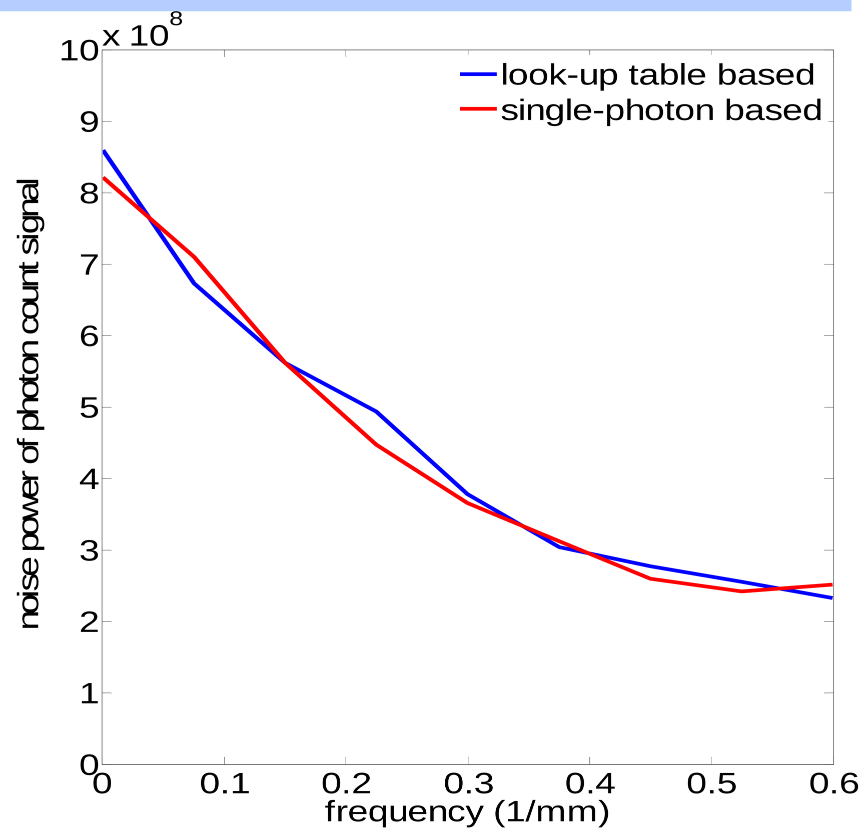

Fig. 4: Diagonal line profile through 2D-NPS

- **Computation time**: 8:15 minutes for this case (approx. 200 times less than a single X-ray photon based approach)

Conclusions

- The Simulation **covers important detector characteristics** that influence signal quality
- The simulation **results are very similar to those of a full scale photon-interaction simulation at much shorter simulation time**
- **Evaluation of a proposed detector design by simulation is feasible**
  - Characteristics like NPS or detective quantum efficiency can be provided
  - Whole CT scans can be simulated with appropriate input sinograms

[1] J. Giersch et al., *Nuclear Instruments and Methods in Physics Research*, A 509, pp. 151-156, 2003

[2] S. Wirth, W. Metzger, K. Pham-Gia, B. J. Heismann, *Impact of Photon Transport Properties on the Detection Efficiency of Scintillator Arrays*, IEEE Nuclear Science Symposium Conference, M11-212, pp. 2602- 2603, 2006