# Realistic CT Image Simulation Tools for Laboratory Based X-ray CT at UGCT

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## ABSTRACT

In laboratory based X-ray Computed Tomography (CT), the grey values in the resulting CT image depend on several scanning conditions such as the emitted spectrum, the response characteristics of the detector and beam filtration. Furthermore, due to beam hardening also the morphology and composition of the sample itself will have a significant influence. Therefore, to optimise scanning conditions simulations which incorporate all factors determining the imaging process are required. In this paper, two programs developed at the Centre for X-ray Tomography of the Ghent University (UGCT) are presented which allow a complete and realistic simulation of the obtained CT image.

## 1. INTRODUCTION

In X-ray Computed Tomography (CT) the grey value of a voxel in the reconstructed CT image is a measure of the linear attenuation coefficient for the materials present in that voxel. The linear attenuation coefficient is the product of the local density and the local mass attenuation coefficient, the latter being dependent on both the element(s) present and the incident photon energy. Laboratory based CT scanners normally use polychromatic X-ray spectra in combination with integrating detectors with an energy dependent efficiency. Therefore, the resulting CT image will vary with the emitted spectrum, the used detector and optional filtration material. Moreover, due to beam hardening, the incident spectrum can be significantly altered while the X-ray beam propagates through the sample, since low energy photons are attenuated more strongly than photons with higher energies. Consequently, the obtained grey values will also depend on size, composition and shape of the scanned object.

Since the mass attenuation coefficient of a chemical element is uniquely dependent on the incident photon energy, often a theoretically ideal scanning energy can be identified to optimise the contrast between different materials in one object. Also for the application of Dual Energy CT (DECT) techniques (Alvarez and Macovski 1976), which combine the information of scans performed at different energies to selectively visualise a specific material, scanning must be done at predefined optimised beam energies. The question that poses itself when using a polychromatic X-ray beam is which spectrum results in the same transmission as a monochromatic beam of the desired energy. This spectrum is determined by many aspects, among which also the beam hardening taking place in the sample. Therefore extensive simulations which incorporate all influencing factors such as emitted spectrum, response characteristics of the detector, filtration material and sample morphology and composition, are required to predict the effects on the resulting CT image.

In this paper, two programs are presented which, when used in combination, allow a complete simulation of the CT images taking all aforementioned variables into account.

## 2. SIMULATION PROGRAMS

### 2.1. Setup Optimizer

The *Setup Optimizer* (Vlassenbroeck 2009) was developed at the Centre for X-ray tomography of the Ghent University (UGCT) to evaluate the influence of different scanner settings. After selecting a specific X-ray tube, tube voltage, beam filtration and detector type, the observed transmission of the polychromatic X-ray beam through a material or combination of materials can be calculated. Furthermore several parameters of the emitted and detected spectrum are computed. To perform the calculations, the photon energy range is split in energy bins, and for each bin the law of Lambert-Beer is applied:

$$I(x,E) = I_0(E)e^{-\mu(E)x}$$

with $I(x,E)$ the intensity of the photon beam which propagated a distance $x$ through the medium with linear attenuation coefficient $\mu$ and $I_0(E)$ the intensity of the incident photon beam both at photon energy $E$. Elemental attenuation data was obtained from the XCOM Photon Cross Sections Database on the website of National Institute of Standards and Technology (NIST; http://www.nist.gov). Monte Carlo simulations were performed in advance using the BEAMnrc program (http://irs.inms.nrc.ca) to generate the X-ray spectra of the different X-ray tubes and response characteristics of the detectors at UGCT.

### 2.2. Projection Simulator

The *Projection Simulator* (De Witte 2010) was developed to simulate projection data for a monochromatic X-ray beam taking all parameters of the scanning geometry into account. This program was extended with Setup Optimizer code to allow the calculation of projection data for polychromatic spectra.

A stack of digital slices, which are all colour-coded to represent different materials, is used as input. Subsequently, a material is allocated to each colour and, similarly to the Setup Optimizer, a specific X-ray tube, tube voltage, detector and beam filtration can be selected. In this way realistic projections can be simulated for different scanning conditions.

## 3. RESULTS

For the following simulation, a directional X-ray tube from Feinfocus, operated at 120kV, and a Varian Paxscan a-Si flat panel detector were selected. A copper filter of 0.1mm thickness was chosen for beam filtration. In figure 1 the resulting spectrum is shown as emitted by the X-ray tube (in black) and as detected by the detector after filtration (in grey). These spectra were simulated with the Setup Optimizer. Note that to obtain the actual observed intensity, the detected spectrum has to be transformed into a detected dose spectrum and integrated.

A stack of 256 identical slices, shown in figure 2a, was used as input for the Projection Simulator. This results in a cylindrical aluminium sample with a diameter of 9.28mm, containing two water cylinders, an iron and an air cylinder. For the simulation, cone beam geometry was used with a source-detector distance of 1m and a source-object distance of 50mm. The resulting voxel size was 0.04mm. In total 900 projections were simulated of which one is shown in figure 2b.

The projections were reconstructed using the in house developed reconstruction program Octopus (Vlassenbroeck *et al.* 2007; http://www.octopusreconstruction.com). Figure 3 shows the reconstructed central slice with a line profile along the indicated white line. Due to beam hardening, there is a clear cupping effect at the edges of the aluminium cylinder. Furthermore metal artefacts from the iron cylinder are visible and grey values clearly vary within the same material, depending on the location in the sample. These are all typical features resulting from the use of polychromatic spectra which demonstrate the realistic character of the simulations.

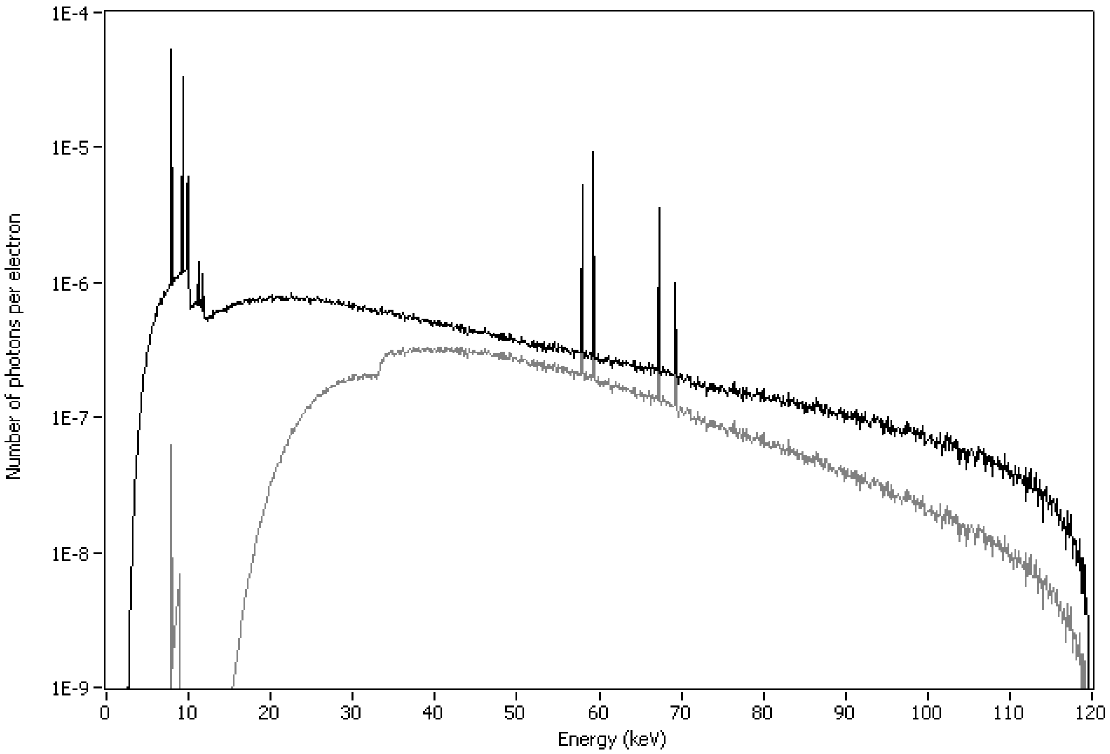

Figure 1: *Spectra simulated with the Setup Optimizer: the emitted spectrum of a directional Feinfocus tube, operated at 120kV (in black) and the spectrum with a 0.1mm copper filtration and detected with a Varian Paxscan flat-panel detector (in grey). Note that to obtain the actual observed intensity, the detected spectrum has to be transformed into a detected dose spectrum and integrated.*

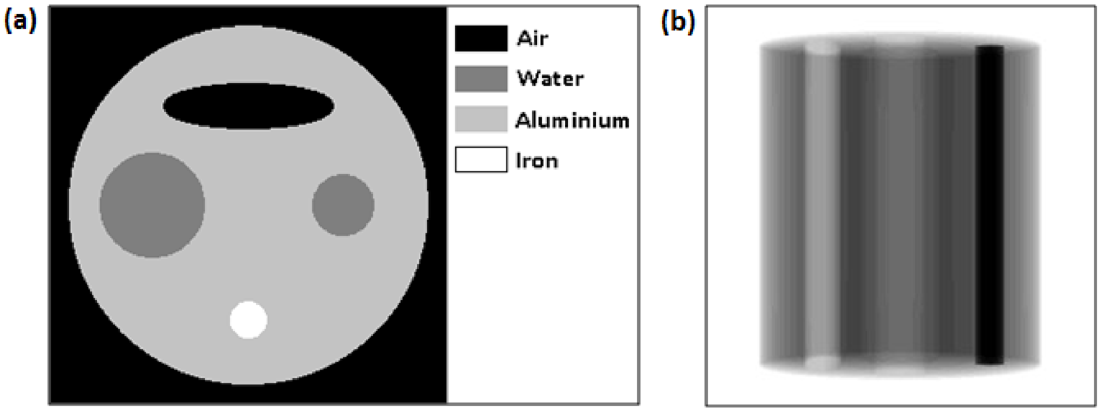

Figure 2: *(a) Input slice for the Projection Simulator and (b) simulated polychromatic projection.*

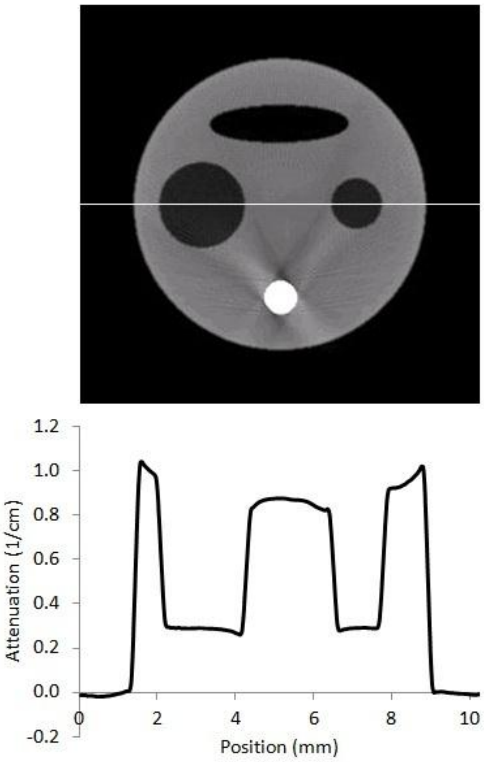

Figure 3: *The reconstructed central slice and a line profile along the indicated white line.*

## 4. CONCLUSIONS

The combination of the Setup Optimizer and Projection Simulator allows a complete and realistic simulation of CT images obtained at the laboratory based CT scanners at UGCT. The effect of each different scanning parameter on the resulting CT image can be investigated which will eventually enable the user to identify optimal scanning conditions for each sample. Furthermore, image processing methods such as artefact reduction algorithms can be evaluated.

## 5. ACKNOWLEDGEMENTS

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