Optimization of scanner parameters for dual energy micro-CT

E. PAUWELS*[1], J. DHAENE[1], A. DE MUYNCK[1] E., M. DIERICK[1], L. VAN HOOREBEKE[1]

[1] UGCT – Dept. Physics and Astronomy, Ghent University, Proeftuinstraat 86/N12, B-9000 Gent, Belgium – Elin.Pauwels@UGent.be
* presenting author

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Abstract

Two materials of different composition can have very similar grey values in an X-ray Computed Tomography (CT). This is because X-ray CT uses polychromatic sources in combination with energy-integrating detectors and the materials have a mass attenuation coefficient that is dependent on composition and photon energy. A distinction between different materials with similar grey values can be made by combining information from scans performed with different spectra, which can be achieved by varying the tube voltage and filtration. However, the polychromatic behaviour of laboratory based X-ray CT complicates the choice of the appropriate scanning conditions for such dual energy methods. Here, the programme Arion, for simulating realistic radiographic projections is used to determine optimal scanning parameters.

Introduction

In X-ray Computed Tomography (CT), the reconstructed sample is represented by a discrete 3D volume. Each voxel in this volume contains a grey value that represents a linear attenuation coefficient µ. This is the product of the local mass attenuation coefficient µ/ρ, which is both energy and material dependent, and the local density ρ of the material, averaged over the detected X-ray energy spectrum. Therefore, the reconstructed linear attenuation coefficients of two materials of different composition can still have similar grey values, making them practically indistinguishable. Since the mass attenuation coefficient of a chemical element solely depends on the photon energy, a distinction between different materials with similar grey values can be made by combining information from scans performed at two or more different X-ray energies. This technique is called Dual Energy CT (DECT).

DECT yields very good results when a (quasi-)monochromatic X-ray source is used which is often the case in synchrotron imaging. However, when using a laboratory-based micro-CT, the polychromatic behaviour of the photon beam and detector sensitivity and efficiency complicates the choice of the appropriate scanning parameters for applications of DECT methods.

A programme for simulating realistic radiographic projection images, Arion (Dhaene et al., 2015), has recently been developed at the 'Ghent University Centre for X-ray Tomography' (UGCT, www.ugct.ugent.be). This programme can also be used to identify optimal scanning parameters for different applications, including DECT.

Methods

A virtual phantom of three aqueous solutions was created and used as a sample. These 3 solutions contained $Pb(NO_3)_2$, PTA and KBr respectively, which are typical staining materials used for the visualization of soft tissue with micro-CT. Simulations were performed for different scanning conditions, which covered a range of voltages (80, 100, 120 and 160kV) and filters (1mm Cu, 1mm Al and 0.1 mm W). Varying these parameters will result in a broad range of different spectra. Covering this range is necessary to find the best signal-to-noise ratio (SNR) or contrast-to-noise ratio (CNR) for the materials inside the phantom for a specific application.

The datasets acquired by the simulations are reconstructed using Octopus (www.octopusreconstruction.com) (Vlassenbroeck et al., 2007), a software package developed at the UGCT. First, all single energy scans were studied in terms of distinctiveness between the three solutions. In most cases at least two out of three materials are not distinguishable. Then a post-reconstruction method (Granton et al., 2008) was applied for the range of simulations. This method allows to combine the information from scans performed at two different energies and calculate the volume fractions of the three materials present in the phantom. In this way, the best settings to perform DECT can be selected.

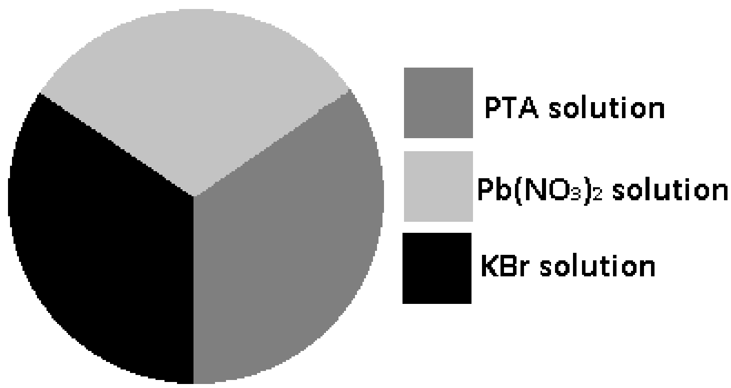

Fig. 1. *Phantom that consists of three aqueous solutions, containing* $Pb(NO_3)_2$ *, PTA and KBr.*

Results

Figure 2 shows the reconstructed attenuation coefficients of the aqueous solutions in terms of tube voltage and filtration and the noise measured on these attenuation coefficients in the slices. It is clear that most settings do not distinguish more than two solutions. Only the scans with 1mm Al at 120kV and 160kV show no significant overlap between the reconstructed attenuation coefficients. Note that the errors shown in the figure represent a one sigma standard error.

Figure 3 shows a reconstructed slice and histogram of the 160kV Al and 80kV Cu scan, which are respectively the best and worst in terms of SNR. At 80kV with 1mm Cu filtration, the three different components cannot be individually identified. As such, they will be visually indistinguishable in a realistic sample where the three materials are mixed. At 160kV with a filter of 1mm Al, the three solutions can be clearly identified in the histogram. However, due to the significant overlap mainly between the peaks of the PTA and KBr solution, segmentation of a real sample where the three materials are mixed, will not be straightforward. The application of DECT could provide a solution for this.

In most cases the $Pb(NO_3)_2$ and KBr solutions can be separated relatively easily. PTA, however, exhibits a different behaviour. It overlaps mainly with $Pb(NO_3)_2$ when using the Cu filter, while it similarly behaves to KBr when using the Al filter. This effect originates in the alterations to the spectrum due to the filtration material. A DECT post-reconstruction method proposed by Granton et al. (2008) was applied for two different cases. This technique allows to combine the information from scans performed at two different energies and calculate the volume fractions of the three materials present (Figure 4). For the first case, the two scanner settings for which PTA differs most from $Pb(NO_3)_2$ (80kV Al) and KBr (120kV Cu) were chosen. For the second case the scanner setting with the best SNR (160kV Al) was selected to replace the 80kV Al setting in the first case. The three solutions can be easily distinguished by using DECT. Despite the better SNR of the 160kV Al setting, the results are better when the 80kV Al setting is combined with the 120kV Cu setting. This indicates that it can be useful to give up on some image quality in a single scan to increase the quality of the analysis when using DECT.

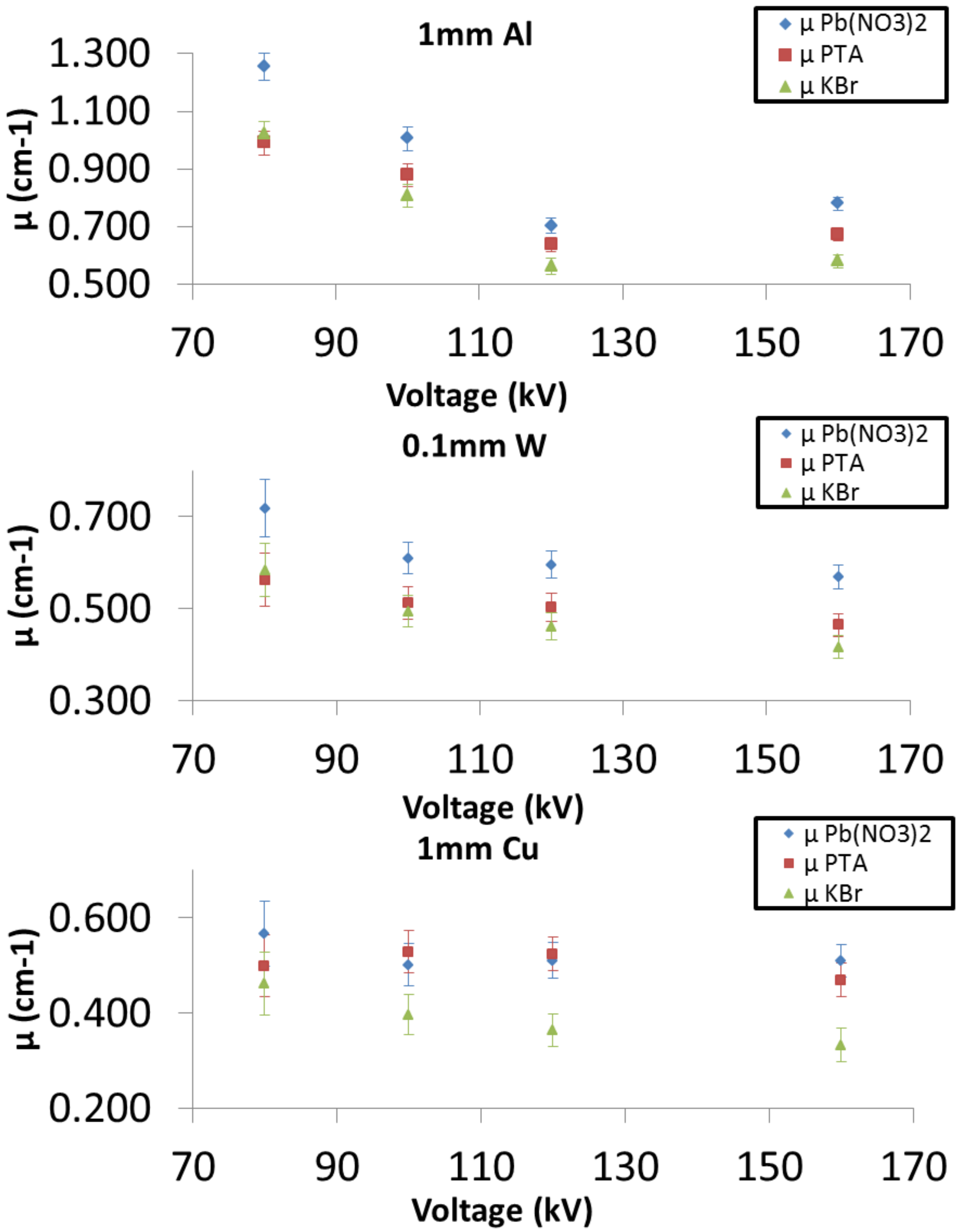

Fig. 2. *The reconstructed attenuation coefficients and their errors(noise) as a function of the tube voltage for the three tested filters.*

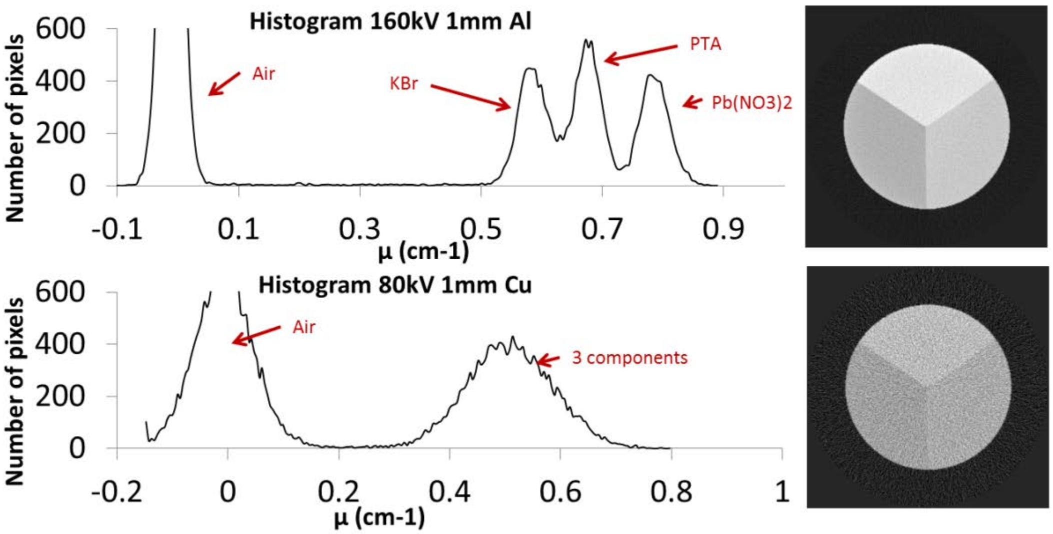

Fig. 3. *The histogram of the reconstructed slices of the scan settings at 160kV with 1mm Al and at 80kV with 1mm Cu.*

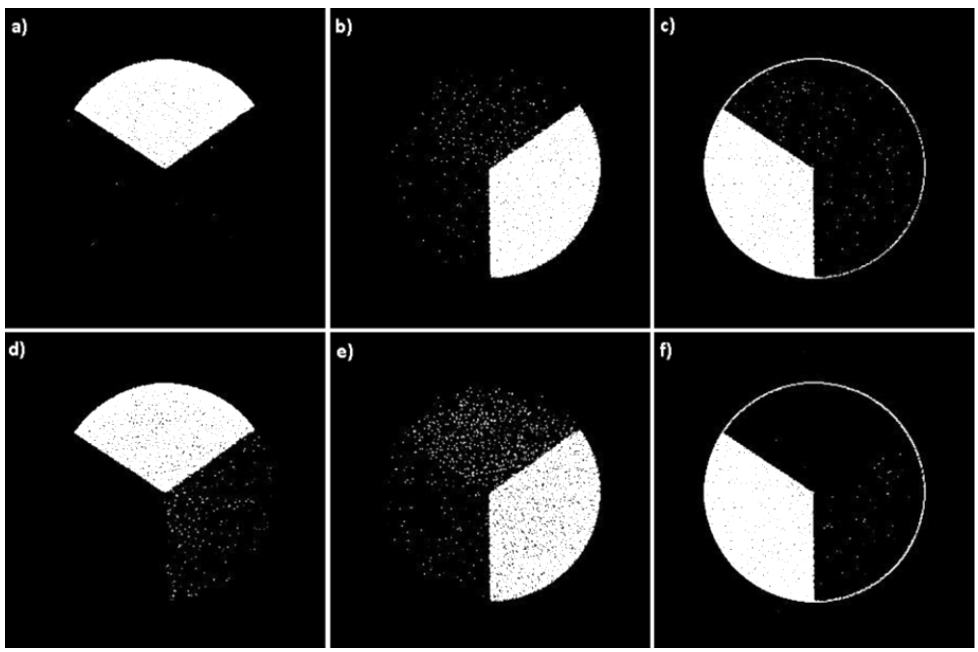

Fig. 4. *DECT applied to the 80kV Al and 120kV Cu slice (a,b & c) and to the 160kV Al and 120kV Cu slice(d,e & f).*

Conclusion

Arion can be used to determine scanning conditions for DECT which optimize the sensitivity for a given element using dual energy techniques. Arion takes into account the energy dependence of the complete imaging chain, including source spectrum, sample size and composition, and detector spectral sensitivity. The applicability was demonstrated on a virtual 3-solution phantom and experimentally validated. It is worth noting that the best settings for discriminating a particular element using a dual energy approach are not necessarily those that offer the best SNR for any particular phase of the sample. It is more important to maximize the difference in reconstructed attenuation coefficient of the material of interest with respect to the other materials present in the sample, taking into account the noise levels for each.

Acknowledgments

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