X-RAY SPECTRUM ESTIMATION FROM TRANSMISSION MEASUREMENTS: PRELIMINARY RESULTS

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Summary: In this study, we propose a method to estimate the polychromatic X-ray spectrum of a microtomograph by measuring transmissions through a series of phantoms with known composition and thickness. An initially lognormal spectrum is iteratively optimized in order to obtain the best fit for all measurements. The validity of the estimated X-ray spectrum is verified based on an independent phantom.

1. INTRODUCTION

Knowledge of the spectral properties of the X-ray source and detector is important for reducing different artefacts as beam hardening but also for developing dual energy analysis. The X-ray source in a lab-based tomography system is polychromatic with a source spectrum $S(E)$. This spectrum is attenuated depending on the properties of the medium through which the X-rays travel. The well-known Beer-Lambert law permits expressing the transmittance T of a tomography system as:

$$T = \int_E S(E)D(E)exp\left[-\int_L \mu\,(E,l)dl\right]d(E)$$

where $D(E)$ is the energy-dependent detector response, $\mu(E,l)$ is the energy-dependent X-ray attenuation map at each position l along the beam path with path length L and E is the photon energy. Source spectrum and detector response can be combined in a single system response spectrum $W(E) = S(E)D(E)$.
Methods of X-ray spectrum estimation can be found in the literature (see e.g. [1]). In this study, we explore the possibility to determine the X-ray spectrum (W) by measuring the transmission through a specially-designed phantom with known composition and thickness in combination with a robust numerical method.

2. MATERIALS AND METHODS

Tomograph: A Zeiss Xradia Versa 510 X-ray microscope was used. This instrument is equipped with a 10W X-ray source with a tuneable energy level between 30 kVp and 160 kVp, The detector is a 4MP 16bit deep-cooled CCD detector which is capable of acquiring radiographs with 2048^2 pixels at a depth of 16 bits per pixel. The Versa 510 permits to enlarge the sample image by geometric magnification and then, a scintillator converts X-rays to visible light, which is then optically magnified via X-ray optics. A 0.4x lens was used in the current study.
Phantom: The phantom is a three-dimensional staircase, machined out of 99.9% pure aluminium. The thickness of each step varies from 0,1 to 1,6 cm every 0,1 cm.
Experimental protocol: The phantom was placed between source and detector. For a given acceleration tension and power, one raw radiograph is recorded for each thickness in absence of a filter. Image corrections were not applied (i.e. no flat field nor dark field). Measurements were repeated at 80, 100 and 120 kV and at a power of 7, 9, 10 W, respectively. The exposure time t was taken constant for each measurement series and equal to the maximum time permitted to avoid saturation of the detector for the smallest thickness. For each radiograph, the transmission T is obtained by averaging the grey scale values of the 8x8 pixels located at the centre of the radiograph. The reference transmission T_0 corresponds to the transmission obtained with the exposure time t_0 without phantom ($t_0 <$

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t). Each transmission T is normalized by T_0 and by the ratiot_0/t.

Spectrum determination: Equation (1) is discretized and converted into a linear system of equations $R_i = A_{ij}W_j$ where R_i are the $n = 16$ measured transmissions after normalisation, W_j are the n samples of the spectrum and

$$A_{ij} = exp\left[-\int_{L_j} \mu\,(E_i, l)dl\right]$$

describes the attenuation of the phantom in a discretized fashion. The attenuation coefficients μ are obtained from the database of the National Institute of Standards and Technology (NIST) [2]. The matrix A is ill-conditioned, rendering a direct solution of the system of equations difficult. Therefore an iterative method was applied, starting from an initial approximation of the spectrum. We employed a lognormal distribution, multiplied by a linear function. The former yields a reasonable form of the Brehmsstrahlspectrum, while the latter ensures that the frequency falls to zero when the photon energy equals the power E_{max} of the generator:

$$W_{ini} = \left(1 - \frac{E}{E_{max}}\right) \ln \mathcal{N}(m, \sigma^2)$$

with $m = \frac{1}{3}E_{max}$ the location and σ^2 the scale parameters of the distribution. This initial spectrum was iteratively refined in order to obtain the best fit for all the measured transmissionsT_i.

Validation: The validity of the discretized spectrum W_j was verified by the estimation of the thickness of a second known phantom, constructed out of 99.9% pure copper.

3. FIRST RESULTS

Figure 1a shows the map of $\mu(E)$ for the atomic element numbers from 1 to 29 and for the acceleration tension from 0 to 160 keV, taken from the NIST database. The measured curves of normalized transmissions R are presented on figure 1b for different acceleration tensions, and figure 1c depicts the corresponding X-ray spectra. The spectrum does not exhibit spectral lines corresponding to the X-ray source target, as the applied sampling (16 samples over the full photon energy range) is too low to detect them. Validation tests on other phantoms are ongoing. Additional tests are in progress to improve the estimation of the X-ray spectrum.

References

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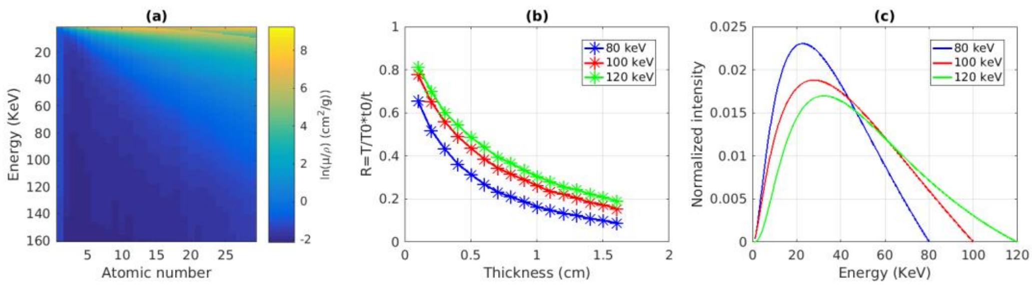

Figure 1: (a) map of μ(E) for atomic element number from 1 to 29 and for the acceleration tension from 0 to 160 keV, (b) curves of ratio T/T0 normalized by t0/t related to the phantom thickness for acceleration tension of 80, 100 and 120 keV, (c) the corresponding estimation of X ray spectrums obtained with each curve of (b).

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