NOVI-SIM: A NEW FAST SIMULATION TOOL FOR X-RAY TOMOGRAPHY

Autret A.[1], Sonzogni A.[1], Guiraud O.[1], Bourgeas J.[1], Fayard B.[1]

[1]Novitom, France

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Summary: X-ray computed tomography acquisitions are time consuming and expensive, when compared to more classical non destructive testing tools. Obtaining the intended image quality requires to optimize the acquisition parameters. In this context, we developed a simulation tool that allows a fast and accurate modeling of the X-ray acquisitions, including the attenuation and phase contrasts.

1. Introduction

The last decade has seen the rise of X-ray computed tomography (CT) as a powerful non-destructive 3D imaging tool. This technique allows for non-destructive 3D digitization of the internal structure of all types of materials or parts. It is now widely used at several scales (sub-micron to sub-millimeter) on all types of pieces or materials: metallic, ceramic, composites... and in almost every industrial sector.

A tomographic acquisition usually consists in collecting 200 to 2000 radiographs which are used as input for the tomographic reconstruction of the 3D volume. The final image quality does not only depend on the number of collected radiographs but also on the exposure time, on the source power, on the tested piece components. If some controls are quite easy (detection of porosities in lightweight materials) some other ones remain quite challenging (visualization of carbon fibers in a polymer matrix, micro-cracks in steel pieces…).

In this context, a simulation tool for tomography (and radiography) control is a key asset. It allows for the calculation of the best experimental parameters and the reduction of the acquisition time while optimizing the data quality. Based on its experience of synchrotron tomography and interaction of X-rays with matter, Novitom has developed a fast simulation tool for X-ray tomography: Novi-Sim. It uses a mixed approach (ray-tracing and wave optics) for fast execution and simulation of a large variety of sources, several detectors and contrast modes: absorption, phase contrast, single distance phase estimation…

This work will introduce the physical and numerical approaches used to perform the simulation of the image formation in radiography and tomography, and will be followed by a comparison of some simulated images with respect to experimental data.

2. X-ray Simulation

Novi-Sim is a simulation software with the GUI shown in Fig. 1(a) that includes X-ray sources (laboratory and industrial) for multiple anode materials and tube voltages, but also synchrotron sources. The laboratory and industrial sources spectra were built using Monte Carlo simulation on the GATE platform [1]. To model a wide variety of X-ray imaging systems, the simulation includes both contrasts, the attenuation as well as the phase contrast, using an approach similar to the models found in [2] or [3]. Contrast arises because the x-ray beam amplitude and phase are modified when the wave propagates through an object. This perturbation is computed using the complex refractive index:

$$n = 1 - \delta + i\beta \qquad (1)$$

where δ represents the phase shift and β the attenuation of the object, which can be calculated using the first and second order atomic form factors from the tabulated NIST database [4]. For a wave propagating along the z axis, the object transmission function can be calculated using this refractive index as follows:

$$q(x,y) = exp\left[\frac{2\pi}{\lambda}\left(\int_{-\infty}^{0} i\,\delta(x,y,z) + \beta(x,y,z)\right)\right] \qquad (2)$$

where λ is the wavelength of the wave. The x-ray wave function on the screen is described by the following equation:

$$\Psi(x,y) = exp\left(i\frac{2\pi}{\lambda}d\right)F^{-1}\left[exp\left(-i\pi\lambda d(u^2+v^2)\right)Q(u,v)\right] \qquad (3)$$

with $F(.)$ representing the Fourier transform operator, Q the Fourier transform of the transmission function and

$d = d_{so}\, d_{oi}/(d_{so} + d_{oi})$ where d_{so} and d_{oi} are the distances from the source to the object and from the object to the image plane respectively. Our simulation exploits a ray tracing approach that allows computing the intersections between the X-rays and the objects modeled by 3D meshes, to compute the object transmission in the equation 2.
The simulation produces quantitative data and exploits the approach described in [5] to compute a realistic noise.

3. Evaluation Study
The experiments were performed at the ID19 beamline of the ESRF, in Grenoble. Radiographs of several test phantoms were measured at different object to camera distances to validate the simulation models of the attenuation and phase contrasts as well as the signal to noise ratio.

4. Results
Results shown a good agreement between simulated and the experimental data of the phase and attenuation contrasts, as shown in the Fig. 1(a), but also with the signal to noise ratio. Novi-Sim allows a fast and accurate simulation of many X-ray imaging systems, to optimise the acquisition parameters and obtain the best image quality without spending time to adjust them during the acquisition procedure.

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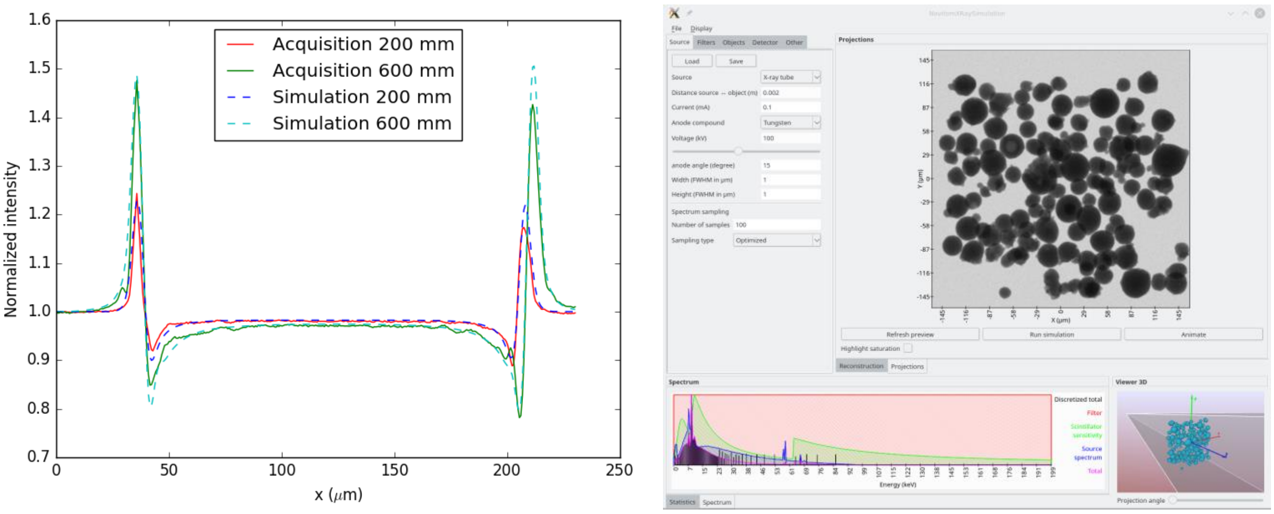

(a) (b)

Figure 1: (a) Profile on measured and simulated radiographs of a 150 μm PEEK wire at 19 keV with a pixel size of 0.65 μm and an object to camera distance of 200 mm and 600 mm. (b) Snapshot of the Novi-Sim GUI.