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Development of semi-classical Monte Carlo techniques for the simulation of clinical grating interferometry breast CT modules

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Introduction

Grating interferometry (GI) breast CT (GI-BCT) aims to improve breast cancer diagnosis utilizing the enhanced soft tissue visibility by combining absorption, phase and dark-field contrast and acquiring three-dimensional data of the uncompressed breast. Due to interference and scattering phenomena in an X-ray GI and the use of incoherent X-ray sources there is no established simulation tool for accurate estimations of image quality, scattering contributions, beam spectra and patient dose, which are important quantities in the design process of clinical GI-BCT modules. Previous approaches to X-ray GI simulations, as for instance Monte Carlo (MC) algorithms implementing Huygens principle, can adequately simulate the required interference phenomena, but mainly struggle with consistent description of all involved processes, modeling incoherent sources, scattering and suffer from long computation times.

Materials and Methods

In this work a MC algorithm was developed based on quantum mechanical principles including classical approximations and implemented as an extension library of the well-established MC particle transport code EGSnrc. As a test for the capability of the developed MC algorithm to simulate interference and attenuation effects, a simplified setup with a sample in front of a silicon pi-phase grating is simulated and the absorption and differential phase images are retrieved. The sample consists of two polystyrene spheres of different sizes, one of which with a silicon core and is illuminated by a monochromatic plane wave in a 1 by 1 millimeter field of view.

Results

The retrieved absorption and differential phase projections have the expected features of the imaging method. The silicon core is clearly visible in both absorption and phase contrast, while the weakly absorbing polystyrene spheres are only visible in the differential phase projection. A performance comparison to an in-house reimplementation of a previously published Huygens principle MC algorithm, in a much smaller simulation volume, shows that the presented algorithm is roughly 2.5 to 25 times faster depending on transport parameter choices.

Conclusion

The newly developed algorithm relies on a consistent physics model of all involved processes and shows desired behavior in academic simulation setups. The quantum mechanical foundation of the algorithm allows to decrease simulation time and the extension to incoherent X-ray sources. Future extensions of the framework will include methods for dose estimation and performance relevant simplifications for the simulation of micrometer sized scatterers required for dark-field simulations.

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