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Recovering refraction and attenuation information in an unknown sample using X-ray propagation-based phase-contrast tomography

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Propagation-based phase contrast X-ray imaging (PB-PCXI) is an experimentally-simple imaging method capable of reconstructing high-resolution images of weakly-attenuating objects, for example, soft tissues in mammography. An X-ray wavefield will be attenuated and refracted as it propagates through a material, this wavefield will then self-interfere such that both attenuation and refraction influence the collected intensity image. These modifications are described by the material's refractive index, $n(\boldsymbol{r}) = 1 + \delta(\boldsymbol{r}) - i\beta(\boldsymbol{r})$, where $\delta(\boldsymbol{r})$ and $\beta(\boldsymbol{r})$ define refraction and attenuation, respectively.

To quantitatively extract sample information, a phase-retrieval algorithm must be applied to the raw intensity data. In the case of PB-PCXI, this algorithm utilizes the Fresnel fringes formed during free-space propagation of the exit-surface wavefield. Paganin *et al.* [1] report the most widely adopted PB-PCXI phase-retrieval algorithm—a single-material approximation to the transport-of-intensity equation. Paganin *et al.*'s approach has been extended to consider multi-material samples [2], incoherent X-ray sources [3], and computed tomography (CT) [4]. These phase-retrieval algorithms can recover the projected phase information of an object; however, they require *a priori* sample information ($\gamma = \delta/\beta$). This may be difficult for cases where sample composition is unknown, as for biological samples.

We propose an alternative phase-retrieval algorithm that can extract $\delta(\boldsymbol{r})$ and $\beta(\boldsymbol{r})$ uniquely for composite materials in an unknown sample [5]. Here, we speak of an unknown sample as no *a priori* sample information is required to successfully implement this approach. The refraction and attenuation extraction method is based on curve-fitting error-functions to unique interfaces within a CT reconstruction of a multi-material sample. The fit parameters are then used to uniquely calculate $\delta(\boldsymbol{r})$ and $\beta(\boldsymbol{r})$ for composite materials in the sample. We applied this approach to PB-PCXI data, collected at the Synchrotron Radiation for Medical Physics (SYRMEP) beamline of Elettra (Trieste, Italy), of a breast-tissue sample. The value of $\delta(\boldsymbol{r})$ for composite materials was calculated to 1.2% - 2.5% accuracy, compared to theoretical values. This approach has the ability to extract distinct sample information without any *a priori* knowledge, and can also be applied to images collected with laboratory X-ray sources.

Keywords – phase contrast X-ray imaging, propagation-based, phase retrieval

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