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Dose-Efficient Propagation-Based X-ray Phase Contrast Imaging at High and Low Resolution by Bragg Crystal Optics

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X-ray phase contrast imaging techniques can visualize weakly attenuating samples such as soft materials or biological tissues by exploiting the phase shift that the sample imprints on the incident wavefield. Propagation-based phase contrast imaging (PB-PCI) exploits the self-interference of the diffracted wavefield behind the sample, which gradually evolves into intensity contrast as the propagation distance between sample and detector increases. In principle, PB-PCI can be employed for imaging at both high, micrometer resolution as well as moderate resolutions of several tens of micrometers. However, both resolution regimes face severe constraints. On the one hand, conventional scintillator-based detectors with micrometer resolution suffer from decreasing efficiency with increasing resolution. On the other hand, imaging large samples at moderate resolution requires tens to hundreds of meters propagation distance to generate sufficient image contrast. Recently, a new beamline has been built at the ESRF to facilitate PB-PCI at remarkably long propagation distances of up to 36 m, tailored to the X-ray source size [1].

We overcome both above-mentioned limitations by employing Bragg crystal optics. For high resolution, a Bragg magnifier allows directly magnifying the X-ray wavefield and using a highly-efficient single-photon-counting detector (SPCD) while maintaining micrometer resolution. The developed system operates close to the theoretical limit of dose efficiency for PB-PCI [2]. We prove the superior imaging performance compared to conventional detector systems and show a substantial increase in dose efficiency for high spatial frequencies that comprise the relevant high-resolution components of the image. Further, we demonstrate the technique' s potential by a pilot in vivo study of submillimeter-sized parasitoid wasps (Fig. 1).

For imaging large, centimeter-sized samples at moderate resolution (several tens of micrometers), we present a new technique that allows achieving strong image contrast within a meter-scale setup, thereby eliminating the need for very long propagation distances [3]. Simultaneously, the technique reduces image blur caused by the finite X-ray source size. The strong increase in image contrast is demonstrated in a proof-of-concept experiment realized by a Bragg demagnifier (Fig. 2). This approach paves the way for low-dose studies of large radiation-sensitive samples, with potential applications ranging from biomedical soft tissue and small animal in vivo imaging up to medical diagnostics, e.g., the early detection of breast cancer.

References:
[1] T. Lang et al., "Multiscale Phase-Contrast Tomography at BM18", e-Journal of Nondestructive Testing 28 (2023)
[2] R. Spiecker et al., "Dose-efficient in vivo X-ray phase contrast imaging at micrometer resolution by Bragg magnifiers", Optica 10.1364/OPTICA.500978 (2023)
[3] R. Spiecker et al., "The Bragg demagnifier: X-ray imaging with kilometer propagation distance within a meter", arXiv:2310.16771 (2023)

Figure captions:
Figure 1: Dose-efficient in vivo imaging at micrometer resolution.
Figure 2: PB-PCI of a large sample at 1 m physical propagation distance for conventional PB-PCI (left) and with the proposed method (right).

I plan to submit also conference proceedings

No

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