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Spectral phase contrast X-ray imaging with high-resolution detectors

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Spectral and phase contrast X-ray imaging techniques have recently emerged as fundamental tools for the improvement of image quality. X-ray spectral imaging (XSI) involves the acquisition of X-ray images at multiple energies, exploiting the energy-dependent nature of X-ray attenuation to provide material composition information. This technique offers an optimal solution for visualizing and quantifying high-Z materials, including contrast elements, due to their peculiar absorption properties at K-edges. Meanwhile, X-ray phase-contrast imaging (XPCI) is an ideal tool to detect subtle density variations within samples. By recording the phase shifts that occur in X-rays as they pass through samples, this technique allows the distinction of features, such as soft tissues, that exhibit low contrast in conventional absorption-based methods. XSI and XPCI are complementary, and their integration has been proven to substantially improve the signal-to-noise ratio and material decomposition of images [1].
The INFN's project Sphere-X has developed a one-of-its-kind setup, implemented at the Syrmep beamline of the synchrotron facility Elettra Sincrotrone Trieste (Italy), to perform simultaneously XSI, utilizing a bent-Laue crystal [2], and XPCI, through the beam-tracking technique [3]. XSI involves acquiring X-ray images across a continuous and spatially dispersed energy spectrum containing the K-edge energy of the materials of interest. This is achieved using a cylindrically bent Laue (i.e. transmission-type) crystal, which energetically disperses the polychromatic synchrotron beam in the diffraction plane. The multiple diffracted energies are vertically mapped on the detector at different pixel rows, allowing simultaneous imaging of multiple K-edges. Quantitative material-specific maps are then obtained using a material decomposition algorithm. In the XPCI beam tracking technique, an absorbing mask shapes the beam into an array of narrow beamlets, each featuring a width in the order of tens of micrometers. The width of the beamlets corresponds to the spatial resolution of the final images. To access phase effects, this technique requires a high-resolution detector having a pixel size below 10µm to accurately track the small shifts of the beamlets, that are induced by the sample. Intensity variations, spatial shifts, and beamlet widths are then extracted to generate absorption, refraction (i.e. differential phase) and scattering images (Fig.2).
The integration of a high-resolution detector in the setup is therefore fundamental for both XSI energy resolution and XPCI signal retrieval. A crucial parameter for assessing the system's sensitivity is the mask modulation, which is defined as the relative difference between the maximum and minimum recorded intensities (Fig.1) in the mask image.
To identify the most suitable detector for the setup, an experimental modulation study was conducted using three distinct scintillator-coupled scientific CMOS imagers. These imagers, named Detector 1, 2, and 3 in this presentation, featured different pixel sizes (7.5µm, 6.5µm and 3.76µm) and different gadolinium-based scintillator thicknesses (10µm, 20µm, 10µm, respectively). The impact of mask modulation on image quality was assessed through a wave optics simulation developed and tested on experimental data. The simulation can predict the outcome for any mask geometry, in terms of period and aperture, and any detector point spread function.
Finally, multiple samples containing silver as contrast element were scanned, both in planar and in tomographic modes utilizing a 300µm thick crystal bent to a radius of 0.5m, together with a 19µm aperture, 116µm period absorbing mask and using Detector 3 (Fig. 2). A 19µm aperture mask was chosen because the 10µm aperture mask used in the modulation study had insufficient modulation.
In this contribution, we describe the experimental setup highlighting the essential requirements of a detector for delivering high-quality images in a combined spectral beam-tracking approach. Moreover, we study the effect of the detector-dependent mask modulation on the retrieval of absorption, refraction and scattering images and showcase the initial results obtained during our first experiments. These results both showcase the feasibility of this technique and pave the way for further optimization towards applications on biological samples.

(attached) Fig 1. Images of 10µm aperture and 61µm pitch mask taken with three different detectors along with their profile plots and modulation parameter.
(attached) Fig 2. Transmission (a), phase (b) and scattering (c) images of the acquired sample. The sample is composed of various flowers, an insect, two silver solutions (10 and 5 mg/ml) and 48□□-diameter PMMA spheres. In (d), the material decomposition image of silver is shown. The images are acquired using Detector 3.

Acknowledgements:

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References:
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