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Unified Modulation Pattern Analysis algorithm (UMPA) for 1D sensitive X-Ray Phase Contrast Imaging techniques

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X-ray phase-contrast imaging (XPCI) techniques give access to phase and small-angle-scattering signals, which are inaccessible to conventional absorption X-ray imaging. Among XPCI techniques, differential phase techniques are based on the measurement of the refraction induced by the sample, which is proportional to the gradient of the phase shift (differential-phase image). By integrating the differential-phase image it is then possible to obtain the 2D map of phase signals (integrated phase image) which, being orders of magnitude greater than the absorption signals, allow increasing the contrast between weakly absorbing features of a sample.

Among XPCI techniques, edge illumination (EI) and grating interferometry (GI) make use of one or more absorbing masks featuring periodically repeated apertures [1]. A different approach to the use of masks is provided by speckle-based imaging (SBI). This latter technique uses a partially coherent X-ray beam and randomly distributed scatterers, such as silicon carbide grit in sandpapers, to create a reference speckle pattern at the detector position [2]. In the usual setups for EI, GI and SBI, both the refraction and the small-angle scattering are extracted by comparing the images of the wavefront markers (masks or speckles) before and after the introduction of a sample in the field of view.

Several algorithms have been proposed to extract the phase information from datasets acquired with EI, GI or SBI setups. However, many of them are application specific, computationally expensive and time consuming [3, 4, 5]. The Unified Modulation Pattern Analysis (UMPA) uses a template-matching approach where a least-squares minimization of a model including transmission, refraction and dark-field signal is carried out for each pixel in the images within a user-defined neighbourhood [6]. A new version of UMPA, written in C++ and Cython, and parallelized with OpenMP, has been recently implemented with the main advantage of being about 120x faster than the previous version implemented in Python. This new implementation of UMPA will be released along with an upcoming publication.

Though the SBI technique has an intrinsic 2D sensitivity to refraction angles, the sensitivity of EI or GI depends on the structure of the mask, which can be 1D (e.g., a bar pattern with fixed period) or 2D (e.g., a grid with fixed period both along the vertical and horizontal axes). The original version of UMPA was designed for datasets that contain refraction along both horizontal and vertical axes. Here, we present a modified version of UMPA to extend its applicability to datasets with sensitivity only along one axis, as is the case with 1D masks. To demonstrate the 1D version of UMPA, we imaged a plant specimen with a beam-tracking setup for EI using a single mask featuring a bar pattern with apertures of 19 µm and 116 µm period. Data were collected at the SYRMEP beamline of Elettra synchrotron (Trieste, Italy) with a polychromatic filtered white beam with an effective photon energy of 21 keV. Images were acquired with a qCMOS camera (ORCA Quest, Hamamatsu) coupled with a 45 µm thick GGG:Eu scintillator and a high numerical aperture optic, whereby the effective pixel size was adjusted to 4.5 µm. Results show that the proposed algorithm is effective in reconstructing the experimental dataset with sensitivity only along the horizontal axis (Figure 1). Furthermore, because of the reduced parameter space, this 1D-UMPA implementation provides a speed-up factor of 2 compared to the original 2D implementation, an especially convenient feature for tomographic datasets.

The UMPA algorithm provides a fast general solution for XPCI techniques making use of masks or speckles in beam-tracking mode, i.e. where the intensity patterns are directly resolved by the detection system. The extension of the original algorithm to the 1D case expands the range of applications to EI and GI setups making use of 1D periodic masks.

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