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P2.60: Time-efficient scanning schemes for x-ray µ-CT with a 2D structured beam

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Introduction. Structuring the x-ray beam into a 2D beamlet array, as shown in Fig. 1, enables three-modal x-ray micro-computed tomography (µ-CT). The beamlets are created by placing an amplitude modulator (mask) with round apertures upstream of the sample [1,2]. Images with the following contrasts can be obtained: attenuation, refraction, and ultra small-angle scattering. Images with contrast based on the refraction channel, are integrated to yield phase-based images. This source of contrast provides 3D information of a sample’ s internal structure which is complementary to attenuation, revealing details which are weakly attenuating and classically have a diminished contrast-to-noise ratio (CNR). Image contrast generated using the ultra small-angle scattering channel enables the visualisation of sample inhomogeneities below the imaging system’ s resolution. The 2D beam structuring provides refraction sensitivity in two orthogonal directions, which reduces inherent image artefacts associated with phase integration. Beam tracking image acquisition [3] allows for the aforementioned three contrast channels to be retrieved from a single frame, with a hardware requirement of a high-resolution detector.

However, a single frame also contains heavily under-sampled data, since the parts of the sample covered by the mask septa cannot contribute to the image. To acquire fully sampled datasets, a “dithering”scheme needs to be applied. Here, the sample is imaged at each dithering step, and an up-sampled image is then obtained by combining the frames. Due to the 2D beam structuring, the sample must be scanned horizontally (along x) and vertically (along y), with a step size equal to, at most, the aperture size, and the full 2D scan must be repeated at each rotation angle. This results in an isotropic spatial resolution driven by the aperture size [4]. While providing adequate sampling, dithering results in long scan times as it cannot be implemented as a fly scan (characterised by a continuous rotation of the sample), but necessitates a step-and-shoot scan, which can be considered time-inefficient as it suffers from non-negligible scan time overheads. On the other hand, without dithering, i.e., if the sample is simply rotated and a single frame is acquired at each angle (a so-called “rotation-only”scheme), the spatial resolution is limited by the mask period [4], and aliasing artefacts may occur.

In our talk, we will report on two different fly scan compatible scanning schemes for x-ray µ-CT with a 2D structured beam (2D beam tracking method), developed to facilitate time-efficient three-modal scans. In addition, the detector requirements for such a method will be discussed.

1.Cycloidal-spiral scanning.
Here, the sample is continuously translated along two-dimensions (both vertically and horizontally), simultaneously with being continuously rotated. As for a rotation-only scan, a single frame is acquired per angular step. However, the “roto-translation”of the sample leads to a much more balanced distribution of the acquired datapoints, providing complementary information; missing data may be adequately restored via a dedicated data-recovery scheme. We have implemented the cycloidal-spiral sampling scheme at the Diamond Light Source (UK) with an sCMOS camera. We investigated the effect of the roto-translation trajectory of the sample and of different data-recovery schemes on the resulting image quality. The results suggest that an optimised cycloidal-spiral data acquisition and analysis scheme enables high-quality µ-CT images to be reconstructed with a spatial resolution which is isotropic and better than that achieved with rotation-only scans (Fig. 2), while also being fully fly scan compatible and therefore time-efficient. Acquired flyscans will be shown in the talk.

2. Isotropic resolution through unidirectional dithering.
We have adapted our mask design to remove the need for vertical dithering by minimising the vertical aperture

separation, while still keeping the beamlets separated to allow for their effective tracking. This is achieved by using a mask that has 1) a horizontal aperture separation longer than the vertical and 2) apertures distributed in a staggered (slanted) manner (offset adjacent rows); the mask design fulfilling the above requirements will the described in the talk. This method offers the potential to fully illuminate a sample with a 2D beamlet array while only applying unidirectional dithering to achieve isotropic sampling in both directions. We implemented this scanning scheme with a laboratory microfocus x-ray source and a CMOS-based flat panel detector. The results of this first proof-of-concept study (Fig. 3) suggest that this simplified sampling scheme is indeed effective. While our initial results were obtained through a step-and-shoot scan, the approach is compatible with cycloidal CT, which is a fly scan compatible (and therefore time-efficient) scanning scheme by which the sample is continuously translated horizontally while simultaneously being continuously rotated [5].

Conclusion. We present two methods that provide a step toward the volumetric investigation of dynamic processes through CT fly scans, while enlarging the range of applications of three-modal tomography.

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[3] F.A. Vittoria et al. Sci. Rep. 5, 16318 (2015). [4] P.C. Diemoz et al. Opt. Express 22, 15514 (2014).
[5] C.K. Hagen et al. Phys. Rev. Appl. 14, 014069 (2020).

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