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Angular sensitivity of 2D phase-sensitive Beam-Tracking X-ray Micro Computed Tomography systems

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X-ray phase contrast imaging is a well-established technique for the non-destructive visualization of low-density samples with applications ranging from biomedical to material sciences [1]. Although originally restricted to synchrotron radiation, extensive efforts have been made to adapt interferometric and non-interferometric methods to non-coherent laboratory X-ray sources [2,3], even for CT [4, 5]. This has enabled multi-contrast tomographic reconstructions of the internal structure of an object.
Most of the developed methods are based on phase or attenuation modulators with 1D sensitivity to refraction. Single 2D structures in the form of phase gratings [6], random phase-modulators [7] and absorption masks [8] have become relevant due to their capability for attenuation, differential phase-contrast, and omni-directional scattering retrieval with a single-shot. Among this, the use of single absorption masks, also referred to as Hartmann wave front sensors [9, 10], has shown potential for the translation towards more compact systems, due to its relaxed coherence requirements and achromaticity.
We have implemented a lab-based X-ray Phase Contrast Micro-CT system with a single two-dimensional absorption mask, which allows for complementary phase and attenuation volumetric representations of a sample. The x-ray source is Hamamatsu micro-focus and the amplitude modulator is obtained from readily available Tungsten foil and with laser-ablation.
The system's working principle is to collimate the beam into a series of periodic beamlets which are resolved by the detector pixels and analyzed independently (see Figure 1). The refraction is retrieved by estimating the sample-induced displacement with a subpixel cross-correlation algorithm, which gives access to two orthogonal phase gradients, allowing a robust and artifact-free phase integration. When used in single shot, the resolution is limited by the mask pitch. However, the system's resolution is ultimately limited by the mask aperture when using sample or mask dithering.
Due to its beam tracking mechanism, micro-focus X-ray sources or small-pitch detector technologies are often required. Photon-counters exhibit low-electronic noise and high-detection efficiency which leads to considerably lower spill-out of the signal in neighboring pixels compared to indirect conversion detectors, allowing to retrieve smaller refraction angles. However, despite significant progress in the past few years, low count-rate and small field of view are still obstacles to translate these technologies towards clinical systems. In this work, we study the angular sensitivity of the Hartmann wavefront sensor implementation with different radiation imaging detectors: a Pixirad-2/PIXIE-III photon-counter with a 650 μm CdTe sensor and 62 μm pitch, a Medipix 3RX photon-counter with a 500 μm Si sensor and 55 μm pitch, and a Hamamatsu Flat Panel detector with indirect conversion from a CsI scintillator and a CMOS sensor. The sensitivity is studied as a function of the system's parameters through modeling and experimental measurements. The relative advantages of each detector technology will be discussed and tomographic reconstructions of samples from engineering and biomedical application fields (as shown in Figure 2 for a piglet-derived oesophagus) will be presented.

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