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Single-mask X-ray multimodal imaging for the investigation of dynamic processes

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X-ray multimodal imaging is based on the retrieval of phase changes and ultra-small angle scattering (or dark-field) in addition to conventional transmission. The availability of these additional contrast channels has already proven to be valuable in many research fields, including medicine and materials sciences, thanks to the ability to provide superior contrast for soft tissues as well as to highlight the internal microscopic structures of objects below the system's resolution. The availability of high flux synchrotron radiation beamlines has recently opened the way to dynamic X-ray imaging with impressive time resolution allowing the investigation of rapidly changing processes. However, dynamic imaging has mainly been limited to conventional absorption or free-space propagation phase imaging. Free-space propagation is not quantitative in single-shot mode unless the sample is homogeneous, which is often a condition not satisfied when investigating the dynamics of a process. On the other hand, the use of quantitative imaging approaches based on gratings or masks poses challenges to a dynamic implementation. This is mainly due to the requirement acquiring frames while displacing one or more optical elements, which may not be compatible with the speed requirements of dynamic imaging. While single-shot methods exist, they typically impose a compromise between time and spatial resolution. To overcome these limitations, we propose a dynamic implementation of the beam tracking imaging method. BT uses a single absorption mask that shapes the beam into a series of beamlets, which are then individually resolved by a detector with a sufficiently small pixel. When a sample is introduced into the beam path, the profile of each beamlet modified by the sample is compared to that obtained without the sample in place to retrieve transmission, refraction and dark-field. The main advantage of BT over other grating and mask-based techniques is the requirement of a single absorption mask, which greatly simplifies the experimental setup. However, when BT is used as a single-shot method, the spatial resolution will be limited by the period of the mask in use, since the separation between adjacent beamlets determines the sampling rate. The way to overcome this limitation is the acquisition of images where the sample is translated by sub-period steps which are subsequently recombined into an image with spatial resolution determined by the mask aperture size. Since only a single movement is required, a dynamic implementation of this method is relatively straightforward and does not pose any demanding hardware requirement. Dynamic BT is based on the continuous translation of the mask in front of the sample, while the detector acquires a sequence of images. The speed of the mask has to be adjusted to match the final required time resolution, considering that to achieve an aperture-limited spatial resolution, the recombination of a number of images equal to ratio between mask period and aperture is required. To investigate the capabilities, the experimental challenges and limitations of this approach, we targeted additive manufacturing and fluid dynamics in two different experiments performed at synchrotron facilities, where we obtained multi-modal images with micrometric spatial resolution and a time resolution of milliseconds

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