PAUL SCHERRER INSTITUT

PSD Mini Symposium

Imaging

Tuesday, December 11, 2018

10:00 to 12:15, WBGB 019

10:00 Implementation of a Monte Carlo simulation tool for grating based imaging setups
Stefan Tessarini, M. K. Fix, W. Volken and M. Stampanoni

10:30 The Heart Imaging Project: phase contrast imaging for cardiovascular applications
Hector Dejea, P. Garcia-Canadilla, I. Planinc, A. Cook, M. Cikes, B. Bijnens, M. Stampanoni, and A. Bonnin

11:00 Coffee break

11:15 Sub-second X-ray tomographic microscopy of liquid water dynamics in polymer electrolyte fuel cells
Minna Bührer, M. Stampanoni, H. Xu, F. Büchi, J. Eller and F. Marone

11:45 Origin of visibility reduction in a Dual phase Interferometer
Amogha Pandeshwar, M. Kagias, Z. Wang and M. Stampanoni

Implementation of a Monte Carlo simulation tool for grating based imaging setups

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Several non-invasive and non-destructive imaging techniques, for instance CT and MRI are widely available and in clinical routine. On the other side x-ray phase contrast imaging [1] (PCI) and dark field imaging (DFI) [2] have become available at synchrotron facilities for various scientific applications. Since PCI and DFI are based on alternative sources of contrast and provide complementary information compared to conventional x-ray absorption techniques, they have the potential to become widely used image modalities in science and clinics. This development raises the need of simulation tools of x-ray grating interferometry systems. Wave propagation algorithms are a valid tool to simulate the interference effects occurring in a grating interferometer, scattering on the other hand is best modeled by MC particle transport codes like EGSnrc [3]. Various approaches to MC simulations of grating based x-ray imaging systems have been presented, implementing different models for diffraction at gratings, including ray-tracing MC [4], full MC methods [5] and hybrid models [6] that split the simulation into a MC and a wave optics part. However, so far no full MC method has been presented that can simulate 3 dimensional centimeter sized field of view setups with polychromatic sources in acceptable computation times.
The focus of this talk will be on the main issues of conventional MC particle transport methods with the simulation of grating interferometers and a Huygens principle MC [7] that serves as a starting point for this PhD.

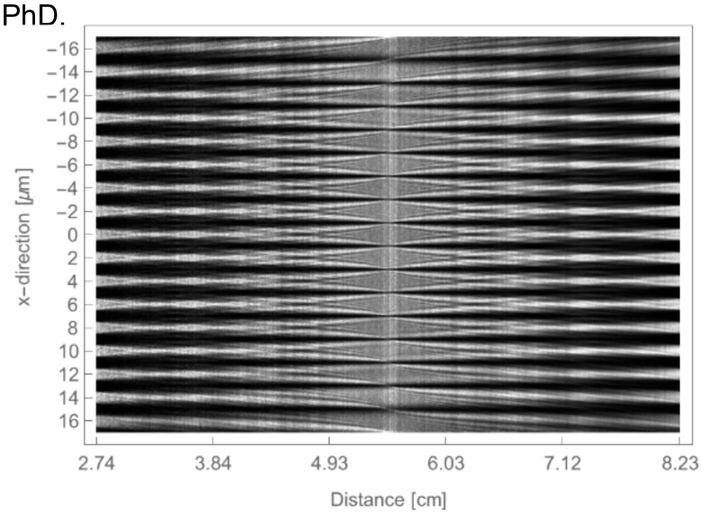

Figure 1. Talbot carpet simulated with a Huygens principle MC.

[1] A. Momose et al., Jpn. J. Appl. Phys., (2013)
[2] F. Pfeiffer et al., *Nature Materials*, (2008)
[3] I. Kawrakow, et al., Technical Report PIRS-701, (2015)
[4] T. P. Millard et al., Rev. Sci. Instrum., (2014)
[5] S. Cipiccia et al., OPTICS EXPRESS, (2014)
[6] S. Peter, P. et al., J. Synchrotron Rad., (2014)
[7] S. Peter, Doctoral Thesis ETH Zürich, (2016)

The Heart Imaging Project: phase contrast imaging for cardiovascular applications

Hector Dejea[1,2], P. Garcia-Canadilla[3], I. Planinc[4], A. Cook[3], M. Cikes[4], B. Bijnens[5,6], M. Stampanoni[1,2], and A. Bonnin[1]

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Cardiovascular diseases (CVDs) are the main cause of mortality in the world, being the responsible for 31% of the population deaths [1]. CVDs can affect the heart and vasculature at all scales, leading to remodelling of the overall cardiac morphology down to alterations on cellular level. It is of prime importance to comprehend the integration of the cardiac microstructural components into larger cardiac structures and how the myocardial organization translates into cardiac function both in physiological and pathological conditions. For a complete assessment of both cardiac macro- and microstructure, 3D non-destructive multi-resolution imaging techniques are necessary to provide high quality information of the changes undergone by the heart - requirements not fulfilled by most of the currently existing imaging methods. This talk will present the developments achieved at the TOMCAT beamline within an international collaboration: new X-Ray Phase Contrast Imaging acquisition strategies as well as image processing tools for the investigation of a wide range of cardiovascular applications. Special focus will be given to the multiscale setup used to image cardiac tissues at different length scales [2]. This will be illustrated with the results obtained for the study of rodent models of cardiovascular fibrosis [3] and myocardial infarct [4], as well as changes in the failing human heart, rejected cardiac grafts and congenital heart diseases in human fetuses [5].

[1] World Health Organization, CVDs Fact Sheet, (2017).
[2] Dejea et al., Scientific Reports, *Submitted*, (2018).
[3] Dejea et al., FIMH, (2017).
[4] Planinc et al., ESC HFA, (2018).
[5] Garcia-Canadilla et al., Circulation Cardiovascular Imaging, (2018).

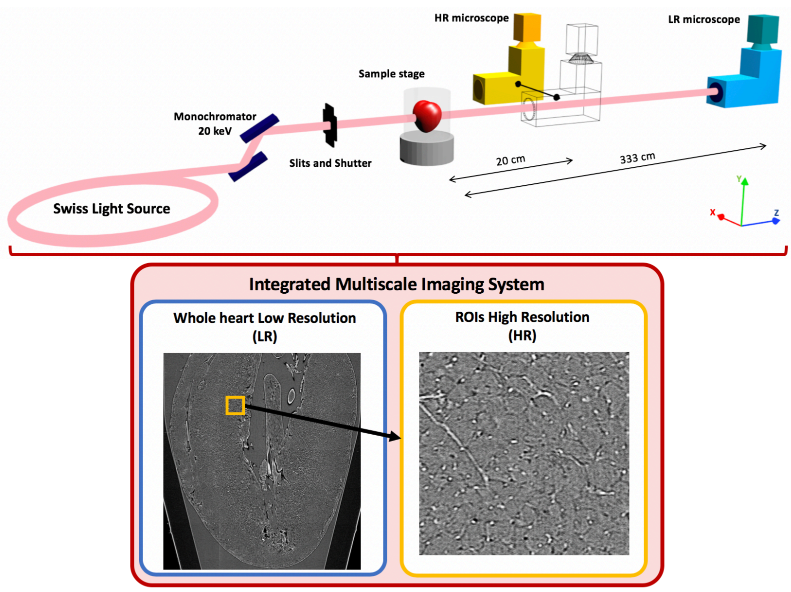

Figure 1. Sketch of the multiscale imaging setup at the TOMCAT beamline.

Sub-second X-ray tomographic microscopy of liquid water dynamics in polymer electrolyte fuel cells

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Fossil fuels are the foundation of our global energy system. Their expected future reduced availability and detrimental effect on climate challenge mankind to seek for alternative energy sources. Polymer Electrolyte Fuel Cells (PEFC) are a key technology in future decarbonized energy systems, but improvements in efficiency, performance, durability and cost are still needed. Sub-optimal water management is a major limiting factor for increasing the power density of PEFC [1].
In this project, the aim is to develop sub-second tomographic microscopy for PEFC to visualize and quantify the liquid water dynamics in the gas diffusion layers (GDL), the key component regulating water management. Tomographic challenges arise from the sensitivity of PEFC to X-ray radiation and, limited signal-to-noise ratio at the short scanning times required for the investigation of PEFC during transient operation.
We will discuss recent advancements both on the hardware and software side. The efficiency and quality of the acquisition setup at the TOMCAT beamline at the Swiss Light Source has been significantly improved with the installation of a new high quality custom-made macroscope [2]. Recent developments based upon a region based SIRT algorithm specific for dynamic studies [3] also show initial promising results: it is for instance possible to reduce the number of projections by at least a factor of 4 with simulated data compared to standard analytical reconstruction routines.

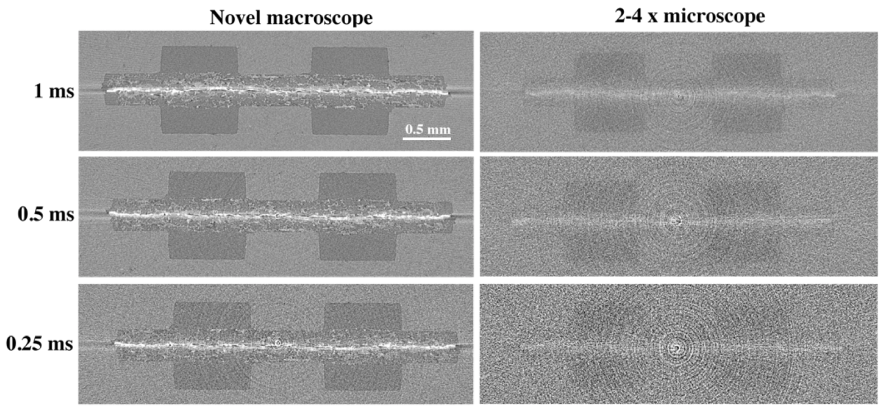

Figure 1 Tomographic slices of a fuel cell sample. Left: reconstructions from novel macroscope images. Right: reconstructions from images acquired with the previously used high temporal resolution setup. For both imaging setups the projection exposure time was from top to bottom 1 ms, 0.5 ms and 0.25 ms. All reconstructions were created from evenly spaced 400 projection images acquired using monochromatic beam energy of 13.5 keV.

[1] J. Eller, F. Marone and F. N. Büchi (2015). Operando Sub-Second Tomographic Imaging of Water in PEFC Gas Diffusion Layers. ECS Transactions 69(17): 523-531.
[2] M. Bührer, M. Stampanoni, X. Rochet, F. Büchi, J. Eller and M. Marone (2018). High numerical aperture macroscope optics for time-resolved experiments. *In preparation.*
[3] G. Van Eyndhoven, K. J. Batenburg, D. Kazantsev, V. Van Nieuwenhove, P. D. Lee, K. J. Dobson, and J. Sijbers (2015). An Iterative CT Reconstruction Algorithm for Fast Fluid Flow Imaging. IEEE Transactions on Image Processing, Vol. 24, No. 11.

Origin of visibility reduction in a Dual phase Interferometer

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X-ray grating interferometer (GI) provides three different contrasts namely absorption, phase contrast and Dark Field (DF). DF is one of these contrasts which has generated a lot of interest as it can provide information about unresolved microstructures in the sample [1]. Recently, a flexible and tunable X-ray grating interferometry setup was proposed [2]. In this setup by changing the distance between the gratings (d), the fringe period is modulated which allows tuning of the length scale sensitivity of the system. This length scale sensitivity can be characterized by correlation length (ξ) ,

$$\xi = \frac{\lambda_{eff} d}{p}$$

Where λ_{eff}, the effective wavelength, and Ls is the sample to detector distance and p is the interference pitch. By changing the distance between gratings (d), the effective pitch changes, thereby the characteristic length changes.

However, a quantitative model is needed to determine the exact structure sizes a particular configuration of GI is sensitive to. In case of a polychromatic X-ray source with wide spectral acceptance of detector, we are able to show the resulting DF originates from two factors, firstly from scattering processes from sub-microstructures present in the sample and secondly from spectral effects. We propose a theoretical model to separate spectral effects from DF to obtain signal originating from microstructures alone. As seen from the figure, with this correction, microspheres of different sizes can be distinguished.

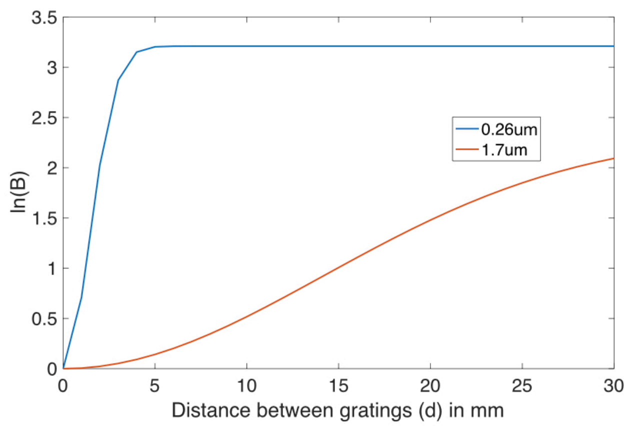

Fig 1: Visibility reduction after removing spectral effects for microsphere solutions

[1]Lynch, Susanna K, et al, “Interpretation of dark-field contrast and particle-size selectivity in grating interferometers”, Applied Optics 50, 4310-4319 (2011)

[2] Kagias, Matias, et al. "Dual phase grating interferometer for tunable dark-field sensitivity." Applied Physics Letters 110.1 (2017): 014105.