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Bimodal imaging at ICON using neutrons and X-rays

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Abstract

For experiments with low contrast between the relevant features it can be beneficial to add a second modality to reduce ambiguity. At Paul Scherrer Institut the two neutron imaging facilities NEUTRA (thermal neutrons) and ICON (cold neutrons) we have installed X-ray beamlines for on-site bimodal imaging with neutrons and X-rays. This allows us to leave the sample untouched in the sample environment throughout an experiment and to reduce the waiting times between acquisitions using each modality. The applications and energy ranges of the X-ray installations are different at the two facilities. At NEUTRA larger samples are intended (60-320kV) and at ICON small samples and simultaneous acquisition are intended (40-150kV). Here, we report the more recent installation at ICON. The X-ray beamline uses a cone beam source and is arranged across the neutron beamline. The beamline is designed to allow up to ten times magnification. This matches the voxel-size that can be achieved with the micro-setup for neutrons. The oblique arrangement of the X-ray beamline further makes real-time acquisition possible since both modalities have a free view of the sample at any time. Reconstruction of cone beam data requires more knowledge about the beam geometry and sample position. Therefore, the beamline is equipped with laser based distance sensors and a calibration procedure has been developed to increase the accuracy of the reconstruction. The purpose of using multimodal acquisition is to fuse the data in a way that enhances the output of the experiment. We demonstrate the current system performance and provide a basic analysis with experiment data.

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Keywords: Neutron imaging; X-ray imaging; computed tomography; bimodal imaging; beamline; calibration

1. Introduction

Applications for bimodal imaging using neutrons and X-rays can be found in many research topics like material testing, fluid flow in porous media, and cultural heritage. This imaging approach is mainly useful when the samples contain material combinations that reveal some complementary information. These differences can be exploited when images from the two modalities are combined. Ambiguities in the image information like low contrast for one modality can be reduced by fusing data from a bimodal image experiment and help the user to better describe the observed sample or process. A further reason to use bimodal imaging is to minimize the impact of artifacts, *e.g.*

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beam hardening, starvation, scattering etc, that are more or less pronounced depending on material composition and modality.

Neutrons and X-rays can both be used to acquire radiographs. The two modalities have different sets of attenuation coefficients that are correlated for some elements while they are uncorrelated for other elements. This makes them an attractive combination for bimodal imaging. Initial bimodal experiments were made using separate imaging facilities which required that the sample was moved to acquire with the second modality Carminati et al. (2006). This approach may be attractive as it makes it possible to obtain images with the best performance for each modality. Unfortunately, this also introduces waiting times and requires transport that may alter the sample. These aspects are of particular importance for porous media experiments were it is important to see the sample with both modalities more or less simultaneously. Encouraged by the results using complementary information provided by the combination during the first combined experiments, we have now installed X-ray imaging capability at our neutron imaging instruments NEUTRA and ICON. The combined installation addresses the issue that the sample has to moved between two facilities and that the installation always is available for the experiment users as an additional method to investigate the sample.

In this paper we will describe the X-ray imaging beamline that is installed at ICON and report some experiences from the first experiments.

2. Instrumentation

2.1. Design

There are basically two different approaches to integrate a second imaging modality to a neutron imaging instrument; in-line and across the neutron beam. These alternatives are schematically shown in figure 1. The inline approach

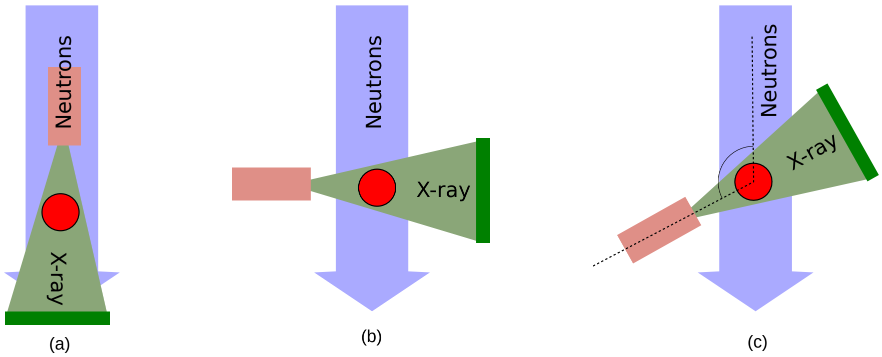

Fig. 1. Approaches to integrate a second modality. The second beamline can be installed in-line with the first beamline (a) or across it (b) and (c). The slanted installation in (c) has the advantage that it minimizes cross-talk and penumbra blurring compared to the perpendicular installation (b).

was chosen at the NEUTRA beamline (Vontobel et al., In review 2016). This installation has the advantage that essentially the same beam geometry applies to both modalities, making pixel-wise comparison possible without the need to register the images on a common coordinate system. On the other hand, simultaneous acquisition is hard to achieve with the in-line approach as the X-ray source hides the neutron source and would also be exposed to the direct neutron beam. At ICON (Kaestner et al., 2011), we chose to mount the X-ray beamline across the neutron beamline with the advantage that simultaneous acquisition is possible. Figure (2) shows the hanging arrangement of the X-ray beamline at ICON. The hanging arrangement was chosen due to space constraints under the neutron beamline. It is possible to mount or dismount of the X-ray beamline within an hour to provide more space for experiments not requiring the X-ray option.

The used X-ray source (Hamamatsu model L212161-07) has a wide cone beam with 43° divergence. The strong divergence of the source defines tomography as the main acquisition mode using X-rays at ICON. Radiography is only relevant for thin samples that are less sensitive to perspective projections. Mounting the X-ray beamline perpendicular