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Phase contrast tomography of human brain using grating interferometry

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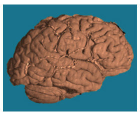
INTRODUCTION



Tomography with micrometer resolution is important to non-destructively obtain the morphology of the human brain without distortions as known from histology. Such a brain atlas is intended to be used in different clinical treatments such as functional neurosurgery. Synchrotron radiation-based micro computed tomography (SRμCT) in absorption contrast mode yields the required spatial resolution but shows hardly contrast for soft tissue as human brain [1]. In order to visualize the human thalamus, especially uncovering the thalamic nuclei which is one of the most ambitious challenges in X-ray tomography, we use SRμCT in the phase contrast mode.

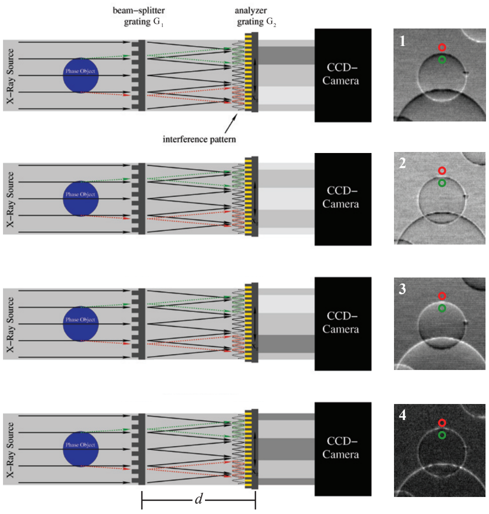
GRATING INTERFEROMETRY

According to the variations of the refractive index inside the brain, the phases of the incoming X-rays change as consequence of deflection. The detection of these phase variances can be uncovered via grating interferometry. Here two gratings are used. The beam-splitter grating (G_1) which is located directly behind the phase object and an analyzer grating (G_2) in a distance d from G_1. The splitting of the incoming X-rays into essentially two diffractive orders forms a periodic interference pattern at distances

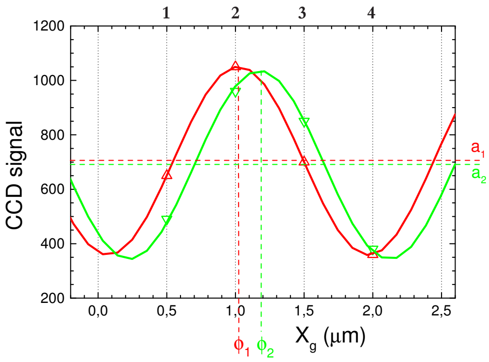
$$d_m = \left(m - \frac{1}{2}\right) \cdot \frac{g_1^2}{4\lambda}, \qquad \text{with} \quad m = 1, 2, 3, \ldots$$

for illuminating plane waves, and $d'_m = \dfrac{L d_m}{(L - d_m)}$

for spherical waves covered a distance L from the source. The period of the analyzer grating should be equal to the period of the interference fringes, so it has to be $g_2 = g_1/2$. The fabrication process of the gratings involves photolithography, deep etching into silicon and electroplating of gold [2].



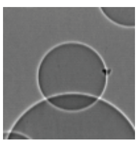
During the grating G_2 drives through a requested number of positions X_g (phase-stepping), the signal can be recorded with a CCD-camera. Depending on whether a maximum or a minimum is at the position of the absorbing material of the analyzer grating, the CCD-camera records a minimum or a maximum of the intensity passing through the analyzing grating. The four images show exemplified resulting interferograms of polysterine spheres [3] at four different analyzer grating positions.



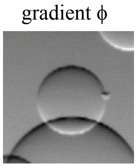
A sine fit on the intensity values of pixel i and comparison with the signal of pixel j yields the phase gradient ϕ_{ij} and the absorption contrast information a_{ij}.

To get the 3D data, the specimen was rotated to record the projections. These images are used for reconstruction by a modified filter kernel in combination with standard filtered back-projection algorithm.

Absorption contrast *a*

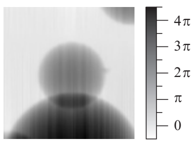


Phase gradient ϕ



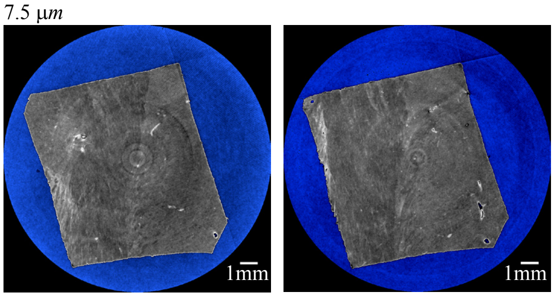
$$\phi = \frac{\lambda d}{g_2} \frac{\partial \Phi}{\partial x}$$

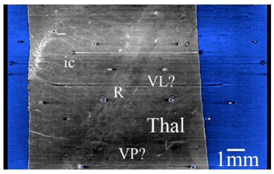
Wave-front phase Φ

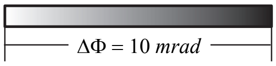


RESULTS

- beamline ID19, ESRF Grenoble
- monochromatic X-ray beam of 26 *keV*
- d=376 *mm* ⟷ ninth fractional Talbot distance
- detection: FReLoN 2K (Fast-Readout, Low-Noise CCD, ESRF) with 2048x2048 pixels with an effective pixel length of 7.5 μ*m*



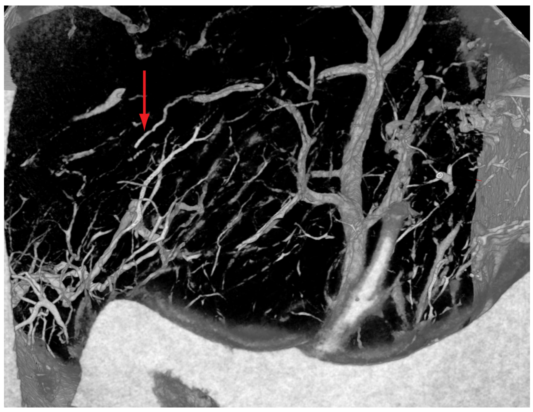




The human brain tissue used in this experiment is a block of a thalamus with a size of 9.5 x 10 x 22 mm^3.

The images above show three of the reconstructed slices. The examination of the reconstructed tomographic slices implies a measurement sensitivity for the real part of the refractive index of $0.7 \cdot 10^{-10}$, which corresponds to an electron density sensitivity of 0.04 e/nm^3. Several anatomical features like nucleus venralis lateralis (VL), nucleus ventralis posterior (VP), reticular thalamic nucleus (R) and inferior colliculus (ic) could be identified. The data have to be compared with histological slices of the investigated block to get additional information on the brainfunction.

The 3-D image below shows a part of the vessel tree inside the brain tissue using intensity-based segmentation without any labeling. The arrowhead indicates a 75 μ*m*-wide vessel [4].



CONCLUSION AND ACKNOWLEDGEMENT

The investigation demonstrates, that phase contrast tomography using a grating interferometer is powerful to image the human thalamus. Different anatomical microstructures of the brain such as white and grey matter or blood vessels were identified. To improve the intensity-based segmentation more sophisticated tools have to be developed.

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