X-Ray Phase Imaging for Medical Applications

X-ray radiographic absorption imaging is an invaluable tool in medical diagnostics and materials science. For biological tissue samples, polymers, or fiber composites, however, the use of conventional X-ray radiography is limited due to their weak absorption. This is resolved at highly brilliant X-ray synchrotron or micro-focus sources by using phase-sensitive imaging methods to improve contrast. The requirements of the illuminating radiation mean, however, that hard x-ray phase-sensitive imaging has until now been impractical with more readily available x-ray sources, such as x-ray tubes. The aim of this project is to develop a method suitable for phase contrast imaging with conventional x-ray tubes.

In conventional x-ray imaging, contrast is obtained through the differences in the absorption cross section of the constituents of the object. The technique yields excellent results where highly absorbing structures, e.g., bones, are embedded in a matrix of relatively weakly absorbing material, e.g., the surrounding tissue of the human body. However, in those cases where different forms of tissue with similar absorption cross-sections are under investigation (e.g., mammography or angiography), the x-ray absorption contrast is relatively poor. Consequently, differentiating pathologic from non-pathologic tissue from an absorption radiograph obtained with a current hospital-based x-ray system still remains practically impossible for certain tissue compositions.

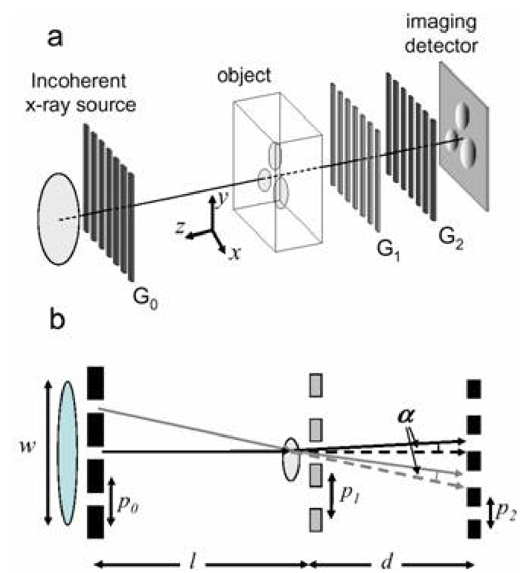

Figure 1: *Talbot-Lau type interferometer.* ***a,b,*** *Principle: the source grating (G_0) creates an array of individually coherent, but mutually incoherent sources. A phase object causes a refraction, which is proportional to the local differential phase gradient of the object. This small angular deviation results in changes of the locally transmitted intensity through the combination of gratings G_1 and G_2. A standard x-ray imaging detector is used to record the final images*

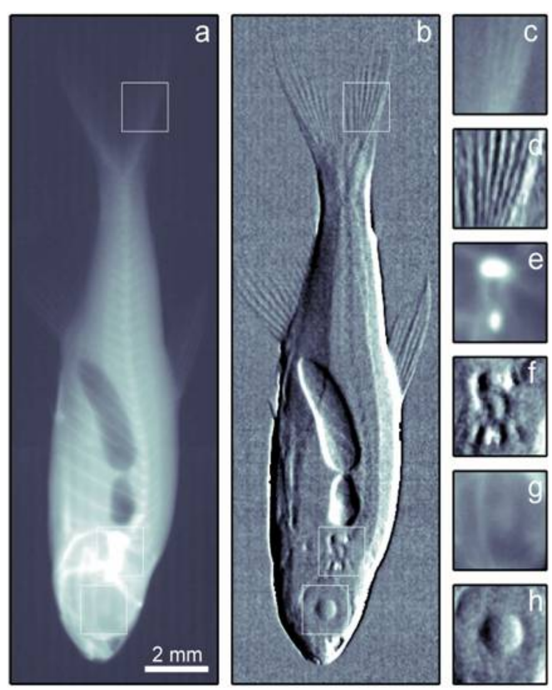

Figure 2: *X-ray images of a small fish. Data recorded with a standard x-ray tube.* ***a,*** *Conventional X-ray transmission image.* ***b,*** *Differential phase contrast image.* ***c-h,*** *Two-times magnified and contrast optimized parts of the transmission (c,e,g) and the differential phase contrast image (d,f,h).*

Figure 2 displays the first results of our method applied to a small fish (Paracheirodon axelrodi). The conventional x-ray transmission image is shown in Fig. 2a, while Fig. 2b contains a greyscale image of the corresponding DPC signal. Both images have been obtained using the same total exposure time, and thus the same dose. As should be expected, the skeleton of the fish and other highly absorbing structures, such as the calcified ear stones (otoliths) are clearly visible in the conventional radiograph (Fig. 2a and e). However, small differences in the density of the soft tissue, e.g., the different constituents of the eye, are hardly visible in conventional absorption image (Fig. 2g). In the corresponding DPC image (Fig. 2h), however, they are clearly visible. Likewise, the DPC image shown in Figure 2f reveals complementary details of the soft tissue structure surrounding the otoliths, whereas only the highly absorbing structures are visible in the corresponding transmission image (Fig. 2e). Finally, we observe that in particular smaller structures with higher spatial frequencies, e.g. the fine structure of the tail fin, are better represented in the DPC image (Fig. 2d) than in the corresponding absorption radiograph (Fig. 2c).

After these first successful demonstration experiments, particular emphasis will be put on the further development of the method with respect to key issues, i.e. the increase of the maximum field of view (presently 64 x 64 mm^2), the adaptation to harder x-rays (> 25 keV), and the combination with computerized tomography. Investigations of medically relevant tissue samples in collaboration with medical research groups will focus on the assessment of the potential improvements in hospital based radiology. Apart from this medically relevant direction we are exploring the possible applications of this novel technique in other research areas, such as non-destructive testing, wave front sensing, archeometry, or phase imaging with massive particles.

Publications

- **Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources**
  Franz Pfeiffer, Timm Weitkamp, Oliver Bunk and Christian David*
  Nature Physics 2, - pp258 - 261 (2006)
  doi:10.1038/nphys265

- **Soft Focus**, *Ed Gerstner*, Nature 440, 619 (2006).

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