Phase tomography with conventional X-ray tube sources

X-ray computed tomography (CT) is an invaluable three-dimensional medical imaging method. The technique yields excellent results where highly absorbing structures are embedded in a matrix of relatively weakly absorbing material (like bones in the tissue of the human body). If, however, the differentiation of weakly absorbing materials, e.g., pathologies in the soft-tissue structure, is the subject of interest, then the contrast achieved by the currently existing, absorption-based X-ray methods is limited, unless contrast agents are used.

Phase sensitive imaging can overcome these limitations and yield good contrast for soft-tissue structures. Phase-contrast imaging relies on refraction, or changes in the angular trajectory of X-rays. Just as light rays bend when they enter water from air, X-rays deflect as they travel through objects of varying densities. As reported previously, this effect can be measured using a *grating interferometer* and detailed radiographic phase-contrast X-ray images can be obtained [see F. Pfeiffer et al., Nature Phys. **2**, 258-261 (2006)].

To extend this two-dimensional *phase-contrast radiography* approach to three-dimensional *phase-contrast computed tomography* (PC-CT), the specimen is rotated around an axis perpendicular to the X-ray beam and several hundred projections are recorded. Using adapted filtered back-projection algorithms, a three-dimensional volume data set of the specimen can be reconstructed in the computer. While PC-CT methods are commonly used as high sensitivity biomedical investigation tools at the SLS and other highly brilliant synchrotron sources, this work focuses on the potential of PC-CT for medical and clinical applications.

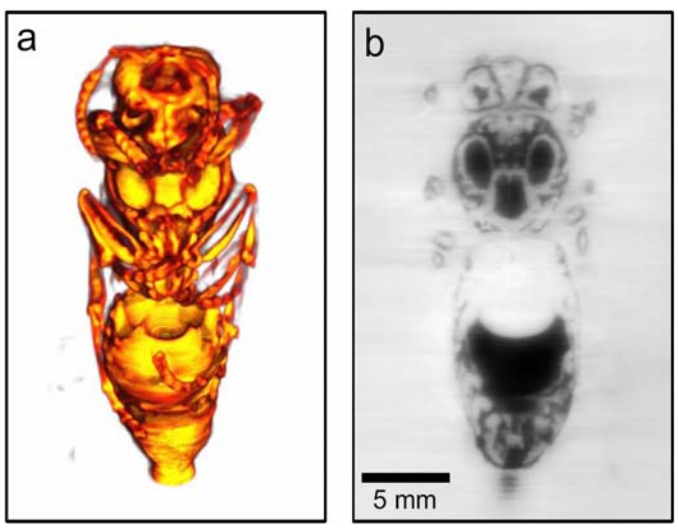

Figure 1: *Post-mortem* phase-contrast X-ray CT results obtained on a large insect (a hornet) using a standard X-ray tube source. a, Three-dimensional rendering of the reconstructed volume data set. **b,** single tomographic slice.

Clearly, clinical applications require the use of standard and commercially available X-ray generators, since it is not feasible to implement high brightness synchrotron sources in a clinical environment or transport all patients to a synchrotron site. In that respect, the experience gained from X-ray PC-CT experiments at the SLS turned out to be crucially important to optimize and further develop the method, until it finally could successfully be transferred, for the first time, to standard X-ray generators.

Figure 1 shows first examples of the successful implementation of PC-CT at a standard lab-based X-ray generator. The specimen used was a large insect (hornet). In particular the tomographic slice through the reconstructed volume data set reveals details of the internal structure of the sample in surprising clarity (Fig. 1b).

The results further illustrate that our method provides an alternative approach for performing X-ray CT scans without the explicit necessity of absorbing X-rays in the object. This is because the phase-contrast signal, which we use to perform the X-ray CT reconstruction, relies on refraction and not on absorption. A further development of the method toward higher X-ray energies, and correspondingly lower absorption, thus has the potential for a significant dose reduction.

These first proof-of-principle results open the way for future medical applications of phase-contrast X-ray CT. Through collaborations with industrial partners, the method will further be developed and may finally yield significant improvements in the soft-tissue sensitivity of medical X-ray imaging applications in a clinical environment.

Publications

- **Hard x-ray phase tomography with low-brilliance sources,**
  F. Pfeiffer, O. Bunk, C. Kottler, and C. David,*
  Phys. Rev. Lett. **98**, 108105 (2007)
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