Optimizing Differential Phase Contrast Data for Tomographic Reconstruction.

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Purpose:

Differential phase contrast (DPC) imaging using a grating interferometer (Figure 1) is an imaging modality which emerged in the last years [1]. The acquisition of projection samples of an object from different view angles allows for tomographic reconstruction [2].
The phase stepping procedure yields three image signals (absorption, differential phase, visibility) (Figures 2 and 3).
Low visibility of extracted phase signals [3] can lead to strong streak artifacts in the reconstructed volume. Here we propose a method which corrects for these artifacts. Therefore redundancies between the phase and the absorption image are used.

Method:

If the visibility V in a certain pixel is small, the extracted phase signal is just a random variable and does not contain any physical information (Figure 4). This can be explained by a decrease of beam coherence by scattered radiation. That means, that pixels with a low visibility do not provide any meaningful information for image reconstruction.
The approach presented here compensates for these missing data by using redundancies between the absorption and the differential phase image. Here the visibility image is used as a quality map of the phase signal.
This results in solving a penalized weighted least square cost function, which leads to a weighted integration of the differential phase data (Figure 5). After applying this procedure standard tomographic reconstruction techniques (filtered backprojection) are used.

Data Acquisition:

The method is evaluated using experimental tomographic grating–based DPC data. The object scanned is a knee of a rat which was infiltrated by a tumor. The used tabletop system is a typical grating interferometer setup with a conventional x–ray tube including an absorption grating. The tube voltage during the measurements was set to 40 kV.

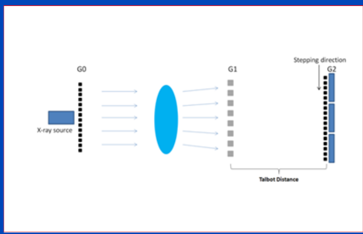

Figure 1: Here a typical setup of a grating interferometer is shown. The grating G0 creates spatially coherent sources. The grating G1 induces a periodic phase shift which is analyzed by the stepping grating G2.

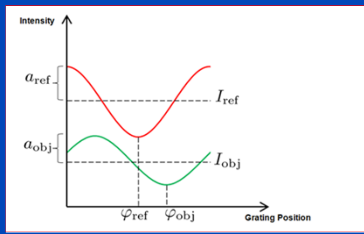

Figure 2: The two curves are a fit on the extracted phase stepping data of a single pixel on the detector. The red curve shows a reference signal without any object in the beam path. The green curve corresponds to a measurement with object.

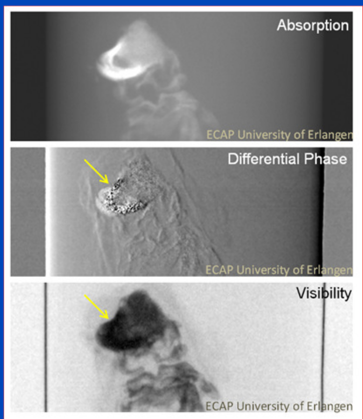

Figure 3: This figure shows the three extracted image signals (absorption, differential phase and visibility). The arrows mark areas of low visibility. Note the high noise in this area in the differential phase image.

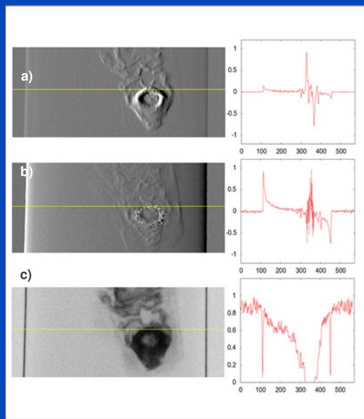

Figure 4: a) Derivative of the absorption image. b) Differential phase image c) Visibility image
The profiles through the low visibility area confirm, that the high frequency pattern in b) is not generated by strong density variations of the object.

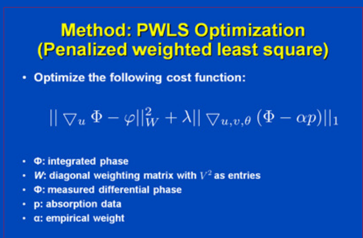

Figure 5: Solving this cost function leads to a weighted integration of the differential phase signal. Here areas of low visibility are replaced by edge information of the absorption image.

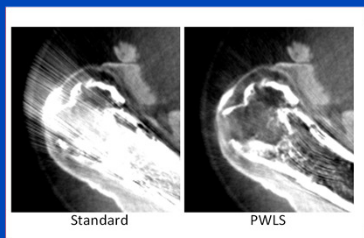

Figure 6 Here an enlarged version of an axial slice of the reconstructed dataset can be seen. Note the reduction of streak artifacts using the proposed PWLS-based reconstruction method. C = 50%, W = 50%.

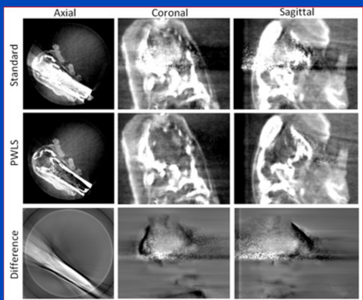

Figure 7:
Here axial, coronal and sagittal slices of the reconstructed dataset can be seen. C = 50%, W = 50%.

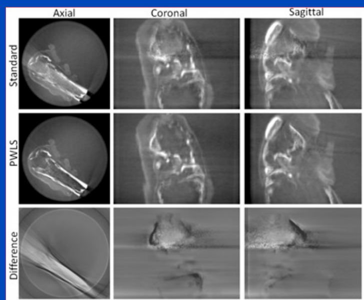

Figure 8:
Here axial, coronal and sagittal slices of the reconstructed dataset can be seen. C = 50%, W = 100%.

To extract the phase and visibility information eight phase steps were performed for each view angle. The number of different projection views is 601. The exposure time per phase step was 6.6 s at a tube current of 50 mA.

Results:

In Figures 6, 7 and 8 one can see the tomographic reconstructions of the acquired dataset. Here a standard reconstruction technique and the proposed method are compared. The reduction of streak artifacts, which are caused by the strong scattering behaviour of the bone, is clearly visible. The difference image shows, that there is no loss in spatial resolution nor any corruption of soft tissue contrast. Figure 6 shows an enlarged area of the axial slice. Here it becomes obvious that the PWLS approach nicely visualizes soft tissue areas which are otherwise corrupted by streak artifacts.

Conclusion:

To our knowledge the proposed method is the first to compensate for uncertainties in grating–based DPC tomography caused by partially low visibility of the input data. This incomplete data problem was solved by the use of redundancies between the integrated phase image and the absorption image.

Acknowledgment:

The high–speed reconstruction software RayConStruct–IR was provided by RayConStruct GmbH, Nürnberg, Germany. We thank the Intel Cooperation and Fujitsu Technology Solutions GmbH for providing their latest multicore hardware.

References:

1. F. Pfeiffer, T. Weitkamp, O. Bunk and C. David, "Phase retrieval and differential phase contrast imaging with low-brilliance x–ray sources," *Nature Physics, no. 2, pp. 258–261, 2006.*
2. F. Pfeiffer, O. Bunk, C. David, M. Bech, G. Le Duc, A. Bravinand P. Cloetens, "High-resolution brain tumor visualization using threedimensional x–ray phase contrast tomography," *Physics In Medicine and Biology, vol. 52, no. 23, pp. 6923-6930, 2007.*
3. T. Weber, P. Bartl, F. Bayer, J. Durst, W. Haas, T. Michel, A. Ritter and G. Anton, "Noise in x-ray grating-based phase--contrast imaging," *Medical Physics, vol. 38, no. 7, pp. 4133-40, 2011.*

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