

Evaluation of phase correction algorithms outside the validity boundaries

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Abstract

In high-resolution X-ray Computed Tomography, the phase shift and refraction of X-rays can under certain circumstances become visible in the projection images, being superimposed on the attenuation images. As such, it can also become visible in the reconstructed volume. This can be beneficiary for the visualization, yet it is often considered an imaging artefact which hinders proper 3D analysis. Under normal experimental conditions, it is mathematically not possible to retrieve the phase information or the attenuation information correctly without multiple acquisitions. However, several methods exist to perform phase retrieval or phase correction, which use assumptions on the object or the imaging setup. In this presentation, the effect of a violation of these assumptions is discussed.

Introduction

In recent years, high resolution X-ray CT (micro-CT) has gained importance in many research domains, including materials science. For low-density materials such as composites or organic materials, the attenuation of X-rays is relatively low, and the real part of the refractive index of materials can provide more image contrast. Several methods have been developed to measure this refractive index accurately, which however usually require highly coherent sources or X-ray optics such as gratings. However, as for visual light, the phase shift induced by the refractive index difference causes refraction, which can be visualized by beam propagation and is as such inherent to the imaging process.

After propagation (within certain limits), the phase shift results in an edge-enhancement effect which is superimposed over the attenuation signal. In the reconstruction process, this phase contrast effect yields artificial effects when left unprocessed. Although this edge enhancement can be beneficial for visual inspection, it often hinders proper analysis and can lead to false conclusions. To correct for or even exploit the phase contrast, several algorithms have been developed to cope with single-image in-line phase contrast data, each with specific advantages and disadvantages.

Methods

The methods discussed in this presentation are the Modified Bronnikov Algorithm (MBA, Groso *et al.*, 2006), the Simultaneous Phase and Amplitude Retrieval (SPAR, Paganin *et al.*, 2002), the Bronnikov Aided Correction (BAC, De Witte *et al.*, 2009) and the Post-Processing Phase Correction (PPPC, Wernersson *et al.*, 2013). The first three are implemented as pre-processing filters, operating on the projection data, the last one is a post-processing method, operating on the 3D reconstructed volume. They are all derived from an inversion of the Transport of Intensity Equation (TIE), which yields an

upper limit for the propagation distance. Furthermore, it is known that these methods all require homogeneous objects in order to reconstruct both phase and attenuation information from only one propagation distance. The MBA method additionally requires a low-attenuating object (Boone *et al.*, 2012).

Results

In this presentation, the influence of a violation of one or more of these requirements is discussed. It is shown that MBA is very sensitive to remaining attenuation in the sample, resulting in a cupping effect (Fig 1. a,c,e). Despite being very similar, SPAR does not suffer from this cupping artefact and can be used for strongly attenuating samples as well. On the other hand, both are affected similarly by heterogeneity of a sample. In this case, the edge enhancement can not be completely compensated in regions where phase inclusions are present (fig 1. c,d), and alternatively strong smoothing occurs for attenuation inclusions (Fig 1. e,f). Similar effects occur for PPC and BAC, although the latter is less prone to image smoothing.

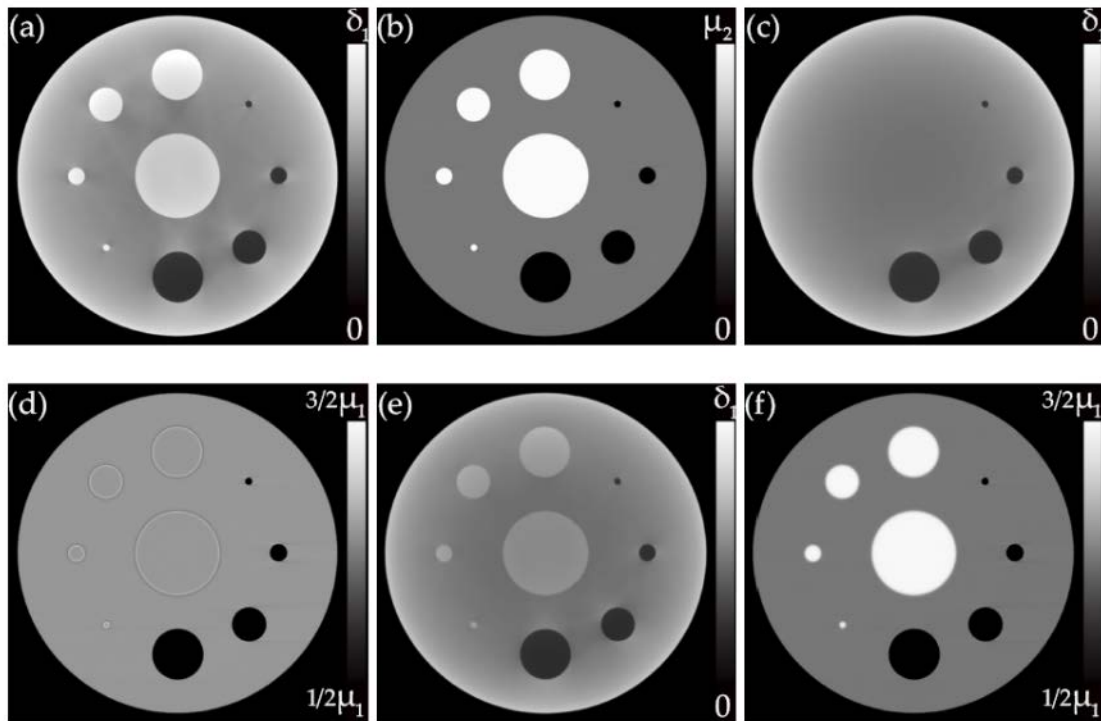


Fig. 1. Reconstructed slices from a phantom (a) homogeneous object, MBA reconstruction; (b) homogeneous object, SPAR reconstruction; (c) sample with phase inclusion, MBA reconstruction; (d) sample with phase inclusion SPAR reconstruction; (e) sample with attenuation inclusion, MBA reconstruction; (f) sample with attenuation inclusion, SPAR reconstruction.

Another parameter which has been investigated is the propagation distance. In lab-based CT, the propagation distance is linked to the geometric magnification and X-ray flux, hence it can not be altered drastically. At synchrotron sources however, the distance between source and object is sufficiently large for these effects to become negligible. Therefore, a relatively homogeneous sandstone sample (Bentheimer) is

scanned at ESRF ID19 at a pixel size of 3.5 μm using different propagation distances, ranging from 30 mm to 1001 mm. As such, the propagation distance and consequently the validity of the TIE is investigated as well.

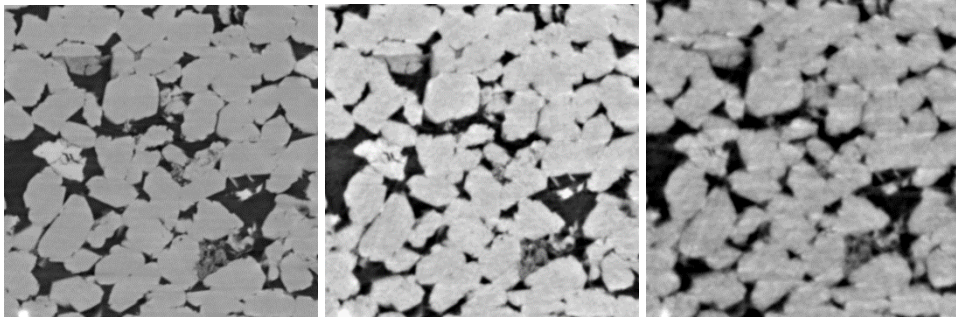


Fig. 2. Reconstructed slices using SPAR phase processing of the sandstone sample at different propagation distances (30 mm, 400mm and 1001 mm, resp.). Note that the gray scale range is different for the largest distance.

Fig. 2 shows a part of a reconstructed slice after phase processing using the SPAR algorithm. The main advantage of this algorithm, particularly at monochromatic radiation, is the physical relevance of the parameters, hence the shown images are considered the optimal phase processing. It is clear that phase retrieval fails at large object-to-detector distances due to the violation of the TIE. A similar result is found for the other phase processing algorithms, where it is in some cases even impossible to determine the optimal parameters for the processing.

Conclusion

It is shown that artefacts occur when the boundary conditions of the phase processing algorithms are violated. In a first place, the requirement of a homogeneous object often hinders proper phase processing in real objects. Furthermore, it is shown that a good selection of propagation distance is required, regardless the low visibility of the phase effects in the projection data at low propagation distances.

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