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Iterative phase retrieval algorithm for medical applications

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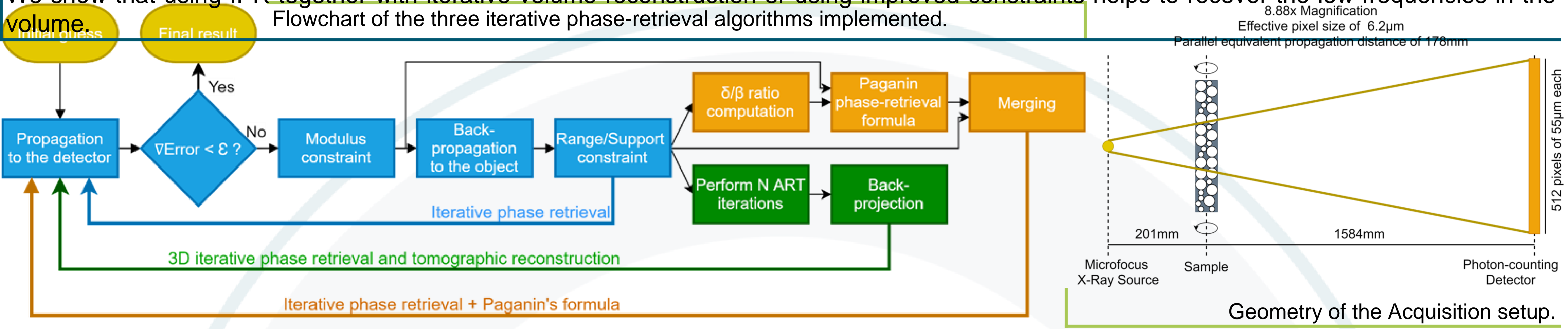
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Context In X-ray medical imaging, phase sensitive techniques are known to provide useful information compared to classical absorption imaging, especially when tissues exhibit weak absorption contrast [1]. A new generation of table-top high-brightness X-ray sources and recent advances in detectors technology makes phase-contrast (PC) imaging using laboratory-scale setups possible, thus paving the way for widespread clinical use.

Goal In this work we are focused on 3D imaging using a propagation based, phase contrast tomography setup. Our goal is to optimize contrast and resolution in the reconstructed volume with a relatively short propagation distance, which keeps the setup compact but is not optimal for phase contrast formation. Direct phase retrieval (PR), such as the Paganin formula (PAG) [1], has proven helpful in medical imaging [2], but requires a priori knowledge of the material. We explore methods based on iterative phase retrieval (IPR) that don't require such a knowledge.

In our conditions, IPR alone is not able to recover low frequencies, but allows to obtain a phase-shift only on string edges. We show that using IPR together with iterative volume reconstruction or using improved constraints helps to recover the low-frequencies in the volume.



The phase-contrast imaging setup We use the free-space propagation in order to achieve phase-contrast, for dose-efficiency and simplicity. The main drawback is optimal propagation distance. Here the sample-to-detector distance is 1.6m and image magnification is 8,9. The source used for the tests is an Excillum MetalJet microfocus with a Ga alloy anode (~50% of spectrum power around 9,25keV). The X-Ray camera is an Advacam WidePix CdTe photon-counting detector with a pixel size of 55 micrometers.

PAG phase retrieval approach can be applied under certain assumptions: the imaged sample is homogeneous and the δ/β ratio must be known. By applying the PAG filter, high frequencies are lost and image contrast is reduced. In order to overcome the limitations produced by this kind of approach:

- + Reader can compute
- + Used in medical imaging
- Single-material
- A priori knowledge required
- High frequencies lost

2D Analytical phase retrieval

The Fresnel propagator (FP) of Ref. [3,4] has been implemented in the IPR method. Unfortunately, the low intensity of PC signal collected with our laboratory set-up still prevent to recover the low frequencies. Additional constraints could be applied to improve the convergence of the algorithm as proposed in Ref. [5,6].

- + Multi-material
- + No a priori knowledge
- CPU intensive
- Inconsistent between projections
- Well reconstructed edges only

2D Iterative phase retrieval

Raw sample radiograph

Capillary filled with silica microspheres

The combination of IPR and tomographic reconstruction [6] makes an important improvement to the convergence of the algorithm. The 3D Volume reconstructed using ART imposes on the IPR the consistency constraint among projections. Compared to 2D IPR, artefacts are less visible, and dynamics are improved.

- + Simultaneous IPR and Recon.
- + IPR advantages
- + Better contrast
- Still edge-dependent
- CPU and memory intensive

3D iterative phase retrieval

2D IPR allows us to estimate the δ/β at each iteration. PAG is used as a constraint at the object plane to calculate the phase-shift. The algorithm converges much faster than IPR. However the final solution is very close to PAG and the multi-material information is lost.

- + δ/β updated at each iteration
- + Fast convergence
- Single-material
- Most high frequencies still missing

2D IPR + PAG constraint

Conclusion IPR algorithms are promising for medical PC imaging but improvements are needed to make it more robust than PAG approach. Two additional constraints could be added to ensure the convergence of the algorithms: the 3D consistency, that has been proven fundamental in the case of IPR, and the PAG constraint for fast convergence without a priori information. Further developments will probably take into account the non-monochromaticity of the incoming radiation preferring a multi-energy phase retrieval approach.

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