



HAL
open science

Comparison of regularized phase retrieval algorithms for x-ray phase contrast tomography - application on experimental data

Loriane Weber, Max Langer, Peter Cloetens, Françoise Peyrin

► **To cite this version:**

Loriane Weber, Max Langer, Peter Cloetens, Françoise Peyrin. Comparison of regularized phase retrieval algorithms for x-ray phase contrast tomography - application on experimental data. 2015 IEEE 12th International Symposium on Biomedical Imaging (ISBI), Apr 2015, New-York, United States. hal-01274021

HAL Id: hal-01274021

<https://hal.science/hal-01274021>

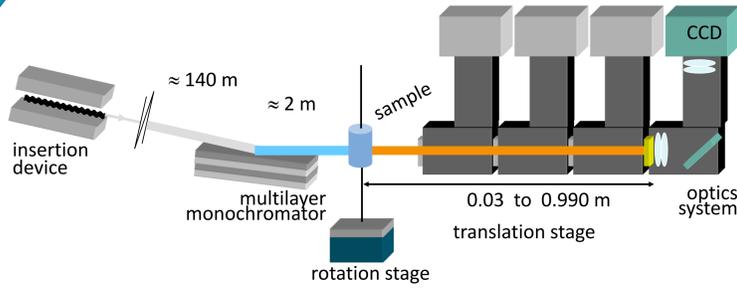
Submitted on 28 Nov 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

In-line phase contrast tomography

Setup: propagation-based parallel beam phase micro-CT



- X-ray phase contrast imaging offers several advantages versus absorption X-ray imaging
- With coherent X-rays, a simple experimental setup based on **propagation** can be used [1]
- Phase contrast is achieved by moving the detector downstream
- The object is modelled by the **complex refractive index** $n=1-\delta+i\beta$, where δ is the refractive index decrement and β the absorption index
- It depends on the material and the energy of the incoming beam. For soft tissue, at low energies (as used in radiology), δ is three order of magnitude larger than β
- Propagation modelled by **Fresnel diffraction**
- In holotomography [1], images are acquired at:
 - several source-to-sample distances
 - under different angles of rotations
- Phase projections** are obtained by combining these multi-distance projections for each angle θ using phase retrieval.

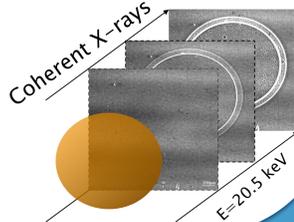


Image reconstruction

- Modeling of the Direct Problem**
 - Attenuation B and phase shift ψ induced by the object described as projections perpendicular to the propagation direction z , with $\mathbf{x}=(x,y)$

$$B(\mathbf{x})=\frac{2\pi}{\lambda} \int \beta dz \text{ and } \psi(\mathbf{x})=\frac{2\pi}{\lambda} \int \delta dz$$
 - At each angle θ , the interaction between the object and the X-ray can be described as a transmittance function

$$T_{\theta}(\mathbf{x})=\exp[-B_{\theta}(\mathbf{x})+i\psi_{\theta}(\mathbf{x})]$$
 - The free space propagation over a distance D can be modeled by the Fresnel transform involving the propagator P_D

$$T_{\theta,D}(\mathbf{x})=(T_{\theta}*P_D)(\mathbf{x})$$
 - The intensity recorded by the detector at a distance D is

$$I_{\theta,D}(\mathbf{x})=|T_{\theta,D}(\mathbf{x})|^2$$
- Inverse problem**
 - Can be split in two steps
 - Phase retrieval:** calculate the phase shift $\psi_{\theta}(\mathbf{x})$ from the phase contrast images at different propagation distances $\{I_{\theta,D}(\mathbf{x}), D=D_1...D_n\}$
 - Ill-posed inverse problem, which requires regularization.
 - $$\hat{\psi}_{\theta}(\mathbf{x})=\arg \min_{\psi} \sum_D [| \hat{I}_{\theta,D,\psi}(\mathbf{x}) - I_{\theta,D}(\mathbf{x}) |^2 + \alpha | \psi_{\theta}(\mathbf{x}) - \psi_{\theta,0}(\mathbf{x}) |^2]$$
 - Tomographic reconstruction:** reconstruct the 3D refractive index image from the phase shifts $\hat{\psi}_{\theta}(\mathbf{x})$ at different projection angles
 - Usually solved by filtered back-projection.

Regularized phase retrieval

Design of prior

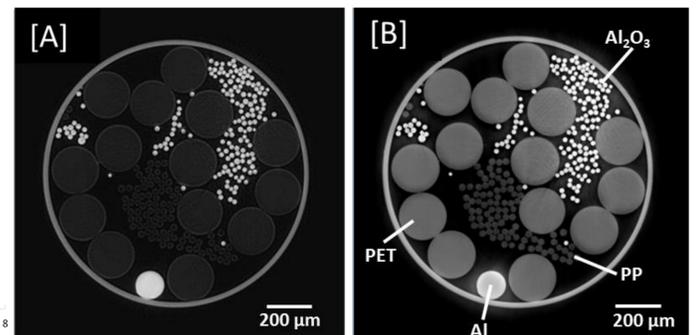
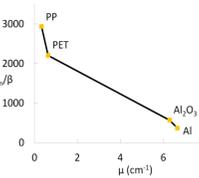
- No prior (i.e. $\psi_{\theta,0}(\mathbf{x})=0$) induces low-frequency noise.
- Possible introduction of **prior** information to alleviate this problem.
- Homogeneous** object: prior is designed assuming that phase is proportional to the attenuation (δ/β -ratio is constant) and applied in the projection domain [3].

$$\psi_{\theta,0}(\mathbf{x})=f(\mathbf{x}) \times \frac{\delta}{2\beta} \ln[I_{\theta,0}(\mathbf{x})]$$

- For **heterogeneous** object of known material, the prior can be designed using several δ/β -ratios:
 - by thresholding the attenuation scan [4]
 - by assuming that the δ/β -ratio is a (continuous) function of the attenuation coefficient [5]

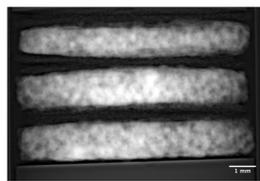
Application on phantom [5]

- Phase retrieval using homogeneous [A] and heterogeneous [B] prior.
- The sample is a phantom composed of multiple wires (Al, PET and PP and Al_2O_3), mounted inside a glass capillary.
- Experimental conditions**
 - 1500 projections
 - 22.5 keV
 - 4 distances
 - Pixel size = 0.7 μm
 - Field of view = 1.4 mm



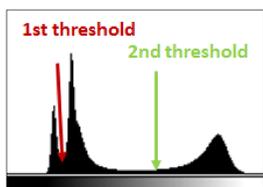
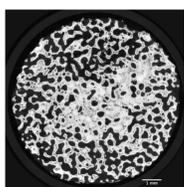
Introduction [6]

- Biomaterial (Skelite[®]) that can be used for 3D cell culture and artificial bone scaffolds in surgery (coll. R Cancedda, University of Genova)
- Composed of Si-TCP(67%) and β -TCP/HA (33%)
- 3 scaffolds imaged: discs of 9 mm diameter, seeded with osteoblasts
- Experimental conditions**
 - 2000 projections
 - 30 keV
 - 4 sample-to-detector distances
 - Pixel size=5 μm
 - Field of view = 10.2 mm

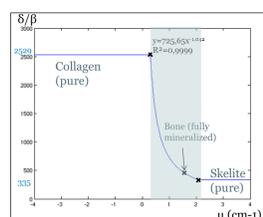


Regularization

- Reconstruction using the **homogeneous approach** (method A) allows quantification of scaffolds but causes artifacts in soft tissue [7]
- We applied 3 **heterogeneous objects approaches** to improve soft tissue imaging
 - Method B (resp. C): using 1st threshold (resp. 2nd threshold)
 - Method D: using a functional relationship between the attenuation coefficient and δ/β values



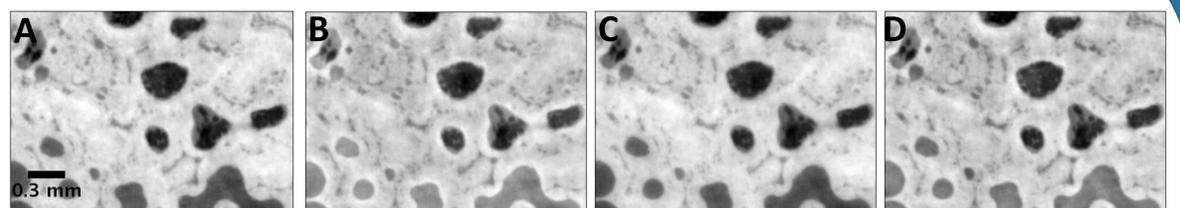
Example of a filtered slice of the attenuation scan, and the corresponding histogram; the histogram is clearly tri-modal, so that 2 different thresholds are possible. They were used in method B and method C.



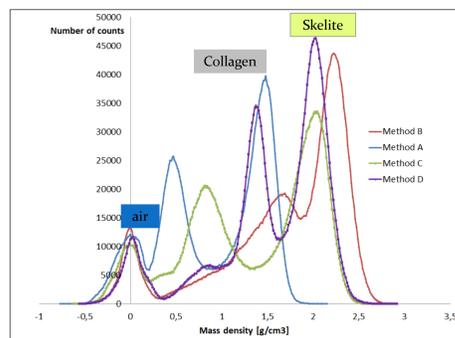
Functional relationship between the attenuation and the δ/β values, used in method D.

Application on 3D cell cultures

Results



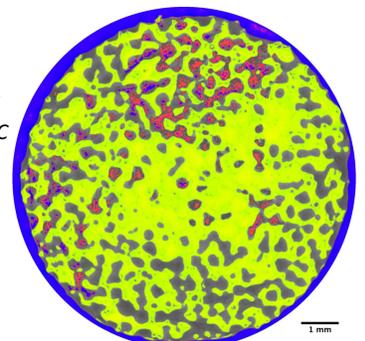
Crop of a reconstructed slice, using homogeneous approach [A], heterogeneous approach with 1st threshold [B] or 2nd threshold [C], and heterogeneous approach with a functional relationship [D].



Histograms of volumetric mass densities of the reconstructed slice with the 4 methods

Theoretical vol. mass densities:

- $\rho(\text{air})=1.3 \times 10^{-3} \text{ g/cm}^3$
- $\rho(\text{Collagen})=1 \text{ g/cm}^3$
- $\rho(\text{Skelite}^{\text{®}})=1.8 \text{ g/cm}^3$



Thresholded slice reconstructed with method C

- Only 3 modes are visible using methods A and B, while we can distinguish 4 modes with methods C and D.
- Method A presents fringes around soft tissue
- Phase contrast artefacts are visible using methods B and D.
- Method C seems more quantitative, and image quality is improved with regards to the other methods.

Conclusions

- Heterogeneous object approaches can clearly improve image quality
- Choice of good parameters (threshold, function) is of crucial importance

Perspectives

- Introduce spatial constraints in prior, i.e. reconstruction while getting rid of the glass capillary
- Further quantitative studies using a calibrated phantom for example.

Acknowledgements

This work was supported by the LABEX PRIMES (ANR-11-LABX-0063) of Université de Lyon, within the program "Investissements d'Avenir" (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR).