Deconvolved phase imaging for diffraction tomography

Yann Cotte[1], Fatih M. Toy[1], Daniel Boss[2], and Christian Depeursinge[1]
1. Ecole Polytechnique Fédérale de Lausanne (EPFL),
Microvision and Microdiagnostics Group (MVD), CH-1015 Lausanne, Switzerland
2. Ecole Polytechnique Fédérale de Lausanne (EPFL),
Laboratory of Neuroenergetics and Cellular Dynamics (LNDC), CH-1015 Lausanne, Switzerland
Author e-mail address: yann.cotte@a3.epfl.ch

Abstract: We present a new technique for coherent imaging based on digital holographic microscopy. For high-resolution tomography, the diffraction effect of the microscope objective is corrected by the system's complex point spread function.
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1. Deconvolution of complex fields

Our experimental setup is built on the technique of digital holographic microscopy (DHM), an interferometric method providing access to the complex wave front [1]. Thus, in off-axis configuration, quantitative phase information can be extracted from single hologram acquisition. In order to achieve high-resolution diffraction tomography, the diffraction effect of the microscope objective (MO) must be taken into account by correcting for the system's complex point spread function [2]. By deconvolution of complex fields, the coherent image formation of image spectrum G can be inverted

$$o(\vec{r}_1) = \iiint_{-\infty}^{\infty} O(\vec{k}) exp[-\mathrm{i}2\pi(\vec{k}\cdot\vec{r}_1)]\mathrm{d}k_x\mathrm{d}k_y\mathrm{d}k_z = \mathcal{F}^{-1}\left\{\frac{G(\vec{k})}{c(\vec{k})}\right\}. \qquad (1)$$

by division through the coherent transfer function c in reciprocal space. As a result, the original object function o is restored. However, the complex division in Eq. (1) suffers from noise amplification for small values in the denominator of c. To effectively avoid this problem, we suggest a complex regularization of c, such as [3]

$$\tilde{c}(\vec{k}) = \begin{cases} c & \text{if } |c| > \tau \\ 1 \cdot \exp\left[\mathrm{i} \cdot \arg\left[c\right]\right] & \text{if } |c| \leq \tau \end{cases}. \qquad (2)$$

Thus, noise amplification can be excluded for τ=1, while the phase part still yields division. The phase deconvolution acts effectively as a subtraction of the diffraction pattern in phase.

2. Results

The effectiveness of our method is presented with a biological sample, fixed human red blood cells (RBC), depicted in Fig. 1.

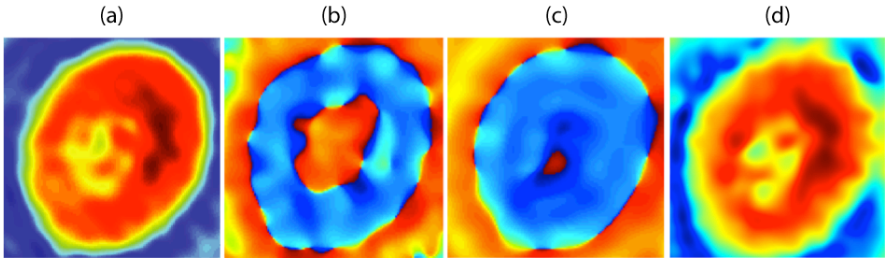

Fig. 1 Quantitative phase images of human red blood cell (RBC). Image (a) shows the raw phase signal while (b-d) show the image after phase deconvolution with regularisation parameter from Eq. (2), τ=0.001, τ=0.01, and τ=1, respectively.

The influence of the phase deconvolution can be seen by comparing these topographic images (a) and (d). Based on their shapes, RBCs are classified in different stages. The raw image in Fig. 1(a) resembles a trophozoite stage while its phase-deconvolved image Fig. 1(d) reveals a ring structure. In Fig. 1(b-c), the phase signal's abrasion by noise amplification is demonstrated as the appearance of phase jumps.

Eventually, similar to coherent imaging ringing, edges are less prone of oscillations after phase deconvolution. Thus, the impact of the complex deconvolution is to ‘de-blur’ the phase signal and processed fields are apt for high-resolution diffraction tomography reconstruction.

3. References

[1] E. Cuche, P. Marquet, and C. Depeursinge, “Simultaneous amplitude-contrast and quantitative phase-contrast microscopy by numerical reconstruction of fresnel off-axis holograms,” Appl. Opt. **38**, 6994–7001 (1999).

[2] Y. Cotte, M. F. Toy, N. Pavillon, and C. Depeursinge, “Microscopy image resolution improvement by deconvolution of complex fields,” Opt. Express **18**, 462–19,478 (2010).

[3] Y. Cotte, M. F. Toy, C. Arfire, S. S. Kou, D. Boss, I. Bergoend, and C. Depeursinge, "Realistic 3D CTF inverse filtering of complex fields," Biomed. Opt. Express **2**, 2216-2230 (2011).