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Deep Gauss-Newton method for phase retrieval

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1 Abstract

The in-line X-ray phase contrast imaging technique relies on the measurement of Fresnel diffraction intensity patterns due to the phase shift and the absorption induced by the object. The recovery of both phase and absorption is an ill-posed non-linear inverse problem. In this work, we present a new learned iterative scheme, the Deep Gauss-Newton algorithm, which is obtained by unrolling [1] a Gauss-Newton scheme. The proposed method combines Convolutional Neural Network (CNN) and knowledge of the imaging physics given by the forward operator and its Fréchet derivative.

In this context, we consider the following inverse problem

$$\mathbf{I}^{\text{obs}} = \mathbf{F}(B, \varphi) + \epsilon$$

where $\mathbf{I}^{\text{obs}}$ is the measured intensity, given by the image of an unknown object with absorption B and phase shift φ, $\mathbf{F}$ the (possibly nonlinear) forward operator and ϵ the noise. Retrieving the couple $f = (B, \varphi)$ can be solved using the Iteratively Regularized Gauss-Newton (IRGN) method [2], which corresponds to iterate on $f_k = (B_k, \varphi_k)$ using the formula

$$f_{k+1} = f_k + H(f_k)^{-1} \left(\mathbf{F}'(f_k)^* [\mathbf{I}^{\text{obs}} - \mathbf{F}(f_k)] - \alpha_k f_k \right)$$

Here, we propose the Deep Gauss-Newton (DGN) method [3], which consists to learn the regularization by replacing the Tikhonov term $\alpha_k f_k$ with a CNN $\mathbf{G}_{\theta^g}$ and to approximate the inverse of the Hessian $H(f) = \mathbf{F}'(f)^* \mathbf{F}'(f) + \alpha \text{Id}$ with another CNN $\mathbf{H}_{\theta^h}$.

We show that taking into account the knowledge of the forward model enhances the quality of the reconstructions and allows a better generalization. Compared to the standard IRGN, the DGN methods both substantially improved the reconstruction and reduced the calculation time. On both simulated and experimental data the DGN permitted improvements of the quality and the resolution compared to another neural network based reconstruction algorithm.

References

[1] Vishal Monga, Yuelong Li, and Yonina C. Eldar. "Algorithm Unrolling: Interpretable, Efficient Deep Learning for Signal and Image Processing". In: *IEEE Signal Proc. Magazine* 38.2 (2021), pp. 18–44. DOI: 10.1109/MSP.2020.3016905.

[2] Simon Maretzke et al. "Regularized Newton methods for X-ray phase contrast and general imaging problems". In: *Opt. Express* 24.6 (Mar. 2016), pp. 6490–6506. DOI: 10.1364/OE.24.006490. URL: http://www.opticsexpress.org/abstract.cfm?URI=oe-24-6-6490.

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