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## Deep image prior for limited-angle electron tomography

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Background incl. aims

Electron Tomography (ET) is a widely used technique for the 3D characterization of nanomaterials. To obtain faithful reconstructions, high-quality projection data must be acquired over the full 180° tilt range and at tilt increments of 1-2°. However, for slab-like sample geometries, the tilt range is often limited due to geometric restrictions within the TEM, and a large tilt increment is used to minimize the total electron dose. These restrictions lead to blurring and distortions in reconstructions obtained with conventional algorithms such as simultaneous iterative reconstruction technique (SIRT). Compressed sensing (CS) approaches have been introduced to improve the quality of reconstructions. Although CS techniques outperform conventional methods in sparse-view acquisition scenarios, they fail to correct artifacts due to the limited angular range. Data-driven deep learning (DL) approaches have been proposed for denoising and distortion correction of X-ray tomography and ET reconstructions. Although promising, these approaches are highly dependent on the availability of high-quality data sets for neural network training. Such data sets are often not available in practice, making it difficult to apply DL methods to a wide range of samples. Recently, Deep Image Prior (DIP) has been proposed for several image restoration problems, and adapted to limited-angle X-ray tomography. The method uses a neural network as a prior for the reconstruction, but has the advantage of not requiring any training data set, making it suitable for ET applications.

Methods

In this work, we apply DIP with total variation regularization (DIP-TV) to a sample consisting of carbon-supported platinum nanoparticles (NPs) dispersed on a carbon grid. ADF-STEM and HAADF-STEM tilt series were acquired from -60° to +60° with an increment of 2°, using an FEI Titan Themis operating at 200kV. In HAADF-STEM projections, only Pt NPs were visible, while in ADF-STEM mode, both Pt NPs and C support were visible but the images were affected by diffraction contrast. DIP-TV was applied for 3D reconstruction in both imaging modes, using increments of 2°, 10° and 20°. Results were compared with those obtained with SIRT and CS with TV regularization (CS-TV).

Results

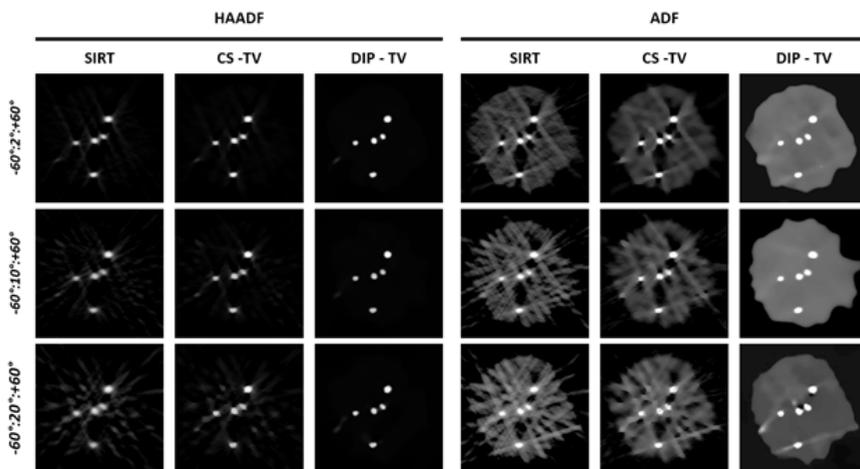
Figure 1 shows the reconstruction of a slice from ADF-STEM and HAADF-STEM tilt series, obtained with SIRT, CS-TV and DIP-TV. The tilt range is [-60°:+60°]

for all reconstructions, with the missing wedge in the horizontal direction, while the tilt increment is set to 2°, 10° and 20°. In HAADF-STEM reconstructions (left), only Pt NPs are visible. SIRT suffers from elongation artifacts and 'star artifacts' as the tilt increment increases. CS-TV slightly improves the quality of the reconstructions but suffers from oil painting effects. DIP-TV reconstructions appear consistent under all acquisition conditions, with near-spherical, well-contrasted particles. The ADF projections are more complex, as the carbon support is visible and superposed on the Pt NPs. SIRT reconstructions suffer from significant artifacts in the support, which increase as the number of projections is reduced. CS-TV still manages to reconstruct the particles, but the carbon is not well retrieved. In particular, for both SIRT and CS-TV reconstructions, the carbon appears heterogeneous and porous below and above each NP. This is probably due to the non-linear intensity in ADF images (diffraction contrast). In contrast, DIP-TV retrieves near-spherical NPs and a homogeneous carbon support, under all acquisition conditions. Using 20° increment (7 projections in total), the shape of the carbon is slightly distorted on the right-hand side, but the technique largely outperforms SIRT and CS-TV.

### Conclusion

This work shows the robustness of DIP-TV for ET using a limited number of projections and a restricted tilt range. The method benefits from the power of neural network architecture, but requires no training data set, making it suitable for ET and extremely versatile since it can be used under different acquisition conditions. Moreover, the method could be applied to different modalities of the same material and potentially directly for 3D reconstruction.

**Graphic:**



**Keywords:**

Electron Tomography, Reconstruction, Deep Learning

**Reference:**

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