Image Denoising of Low-Electron-Dose Transmission Electron Microscopy

2021 Winter EE367 Project Proposal

Zewen Zhang

Department of Materials Science and Engineering

Stanford University, Stanford, CA, 94305

1. Motivation

Transmission electron microscopy (TEM) are powerful tools for atomic-resolution structural analysis, which is critical to the understanding of structure-property relationship in materials science. However, electron microscopy study of weakly bonded or reactive materials, such as organic-inorganic hybrid perovskite and metal organic framework, have been hindered by their rapid structural degradation under intense electron beam. In this regard, fast acquisition and low electron dosage are desired to minimize the beam-induced effects. However, lowering the electron dose decreases the signal-to-noise ratio (SNR) of the acquired micrographs, degrading the quality or even completely prohibiting the extraction of desired critical information from the noisy images.

In this work, we propose to investigate image denoise methods for low-electron-dose TEM images. Specifically, we will explore different types of denoise methods, and probably mainly focus on methods that can exploit the periodic structure nature of crystalline materials, and further tailor these methods to simultaneously handle both periodic and non-periodic deviation at defect areas properly.

2. Related Work

2.1 TEM image denoising

Denoising in TEM for materials science is often accomplished by simple spatial filters like Bragg filter[1], Wiener filters[2], Gaussian filter[3], or their combinations. These methods are often employed for images from materials robust enough to survive high electron dose to obtain high spatial oversampling.

2.2 Generic Image Denoising

One of the most popular generic image denoising method for arbitrary images available today rely on non-local detection and averaging of self-similar image regions, which is proposed by Buades et al., where they proposed a non-local means (NLM) filter.[4] Since TEM images of crystalline materials are rich in self-similarity, NLM is in principle well suited for denoising such micrographs, and it has been applied to TEM images for biological samples.[5] This strategy can be further extended by replacing the weighted average of intensities of pixels with similar neighborhoods by more advanced collaborative filtering. Block match and 3D filtering (BM3D) algorithm was one of the most successful variant.[6]

3. Project Overview

This project plans to explore, develop and evaluate image denoising methods for low-electron-dose TEM images of crystalline materials. We will first explore some of baseline image processing methods for traditional high resolution TEM images, and then focus on non-local detection methods such as NLM, BM3D and relevant variations, and further adapt them for low-electron-dose TEM images of crystalline materials.

3.1 Low-electron-dose TEM image

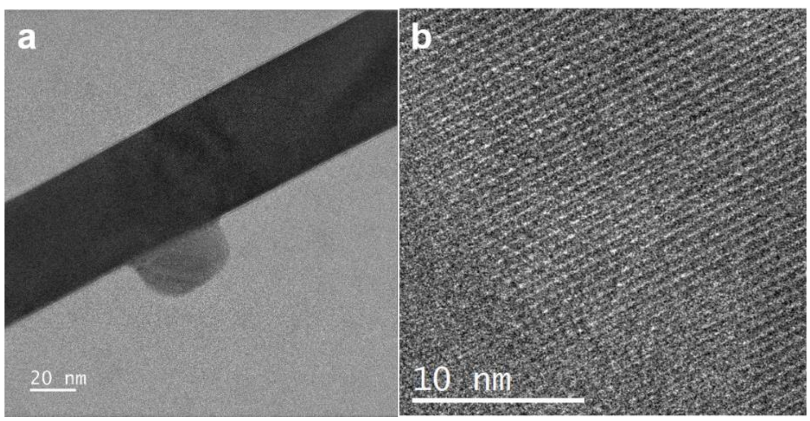

Figure 1 | **a**, cryogenic transmission electron microscopy (cryo-TEM) image of hybrid halide perovskite nanowire ($MAPbI_3$) **b**, zoomed-in region of nanowire in **a**.

We will use low-electron-dose image of hybrid halide perovskite nanowires taken with Thermo Fisher Tecnai F20 TEM equipped with a Gatan K2 direct-detection camera in the electron-counting mode with the dose fractionation function. The image was taken with e^-/Å2/s (Figure 1).

3.2 Denoise Algorithm

The noise induced in TEM is non-additive and signal dependent. In low-electron-dose TEM images, the noise can be modeled by Gaussian distribution, Poisson distribution, or a mixed of both, depending on the total electron dosage and detectors. So here for non-local detection-based methods, we will explore different extensions to various types of noise and try to determine which one best suits crystalline materials at given range of electron dosage.

4. Milestones, Timeline and Goals

There are 4 weeks for this project. In the first week, I will work with some non-linear denoise methods, explore their combinations and evaluation their performance. In the second week, I will implement and optimize basic NLM and BM3D methods. In the third week, I will work to tailor BM3D for this specific type of image and see if what kind of modification will give a better result. For the last week, I will continue to refine the project and summarize it into a poster and a project report.

The baseline for this project is the traditional methods used in high resolution TEM image denoise. The aim is to achieve better denoise performance with new algorithms customized for low-electron-dose TEM images for crystalline materials, where ideally we want to distinguish each individual atom columns in the micrograph clearly. At the same time, it's also important to develop understanding about the noises in this type of images by comparing different algorithms.

Reference

[1] A. F. De Jong, W. Coene, and D. Van Dyck, "Image processing of HRTEM images with non-periodic features," *Ultramicroscopy*, vol. 27, no. 1, pp. 53–65, Jan. 1989, doi: 10.1016/0304-3991(89)90200-3.

[2] L. D. Marks, "Wiener-filter enhancement of noisy HREM images," *Ultramicroscopy*, vol. 62, no. 1, pp. 43–52, Jan. 1996, doi: 10.1016/0304-3991(95)00085-2.

[3] O. L. Krivanek *et al.*, "Atom-by-atom structural and chemical analysis by annular dark-field electron microscopy," *Nature*, vol. 464, no. 7288, Art. no. 7288, Mar. 2010, doi: 10.1038/nature08879.

[4] A. Buades, B. Coll, and J.- Morel, "A non-local algorithm for image denoising," in *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)*, Jun. 2005, vol. 2, pp. 60–65 vol. 2, doi: 10.1109/CVPR.2005.38.

[5] D.-Y. Wei and C.-C. Yin, "An optimized locally adaptive non-local means denoising filter for cryo-electron microscopy data," *J. Struct. Biol.*, vol. 172, no. 3, pp. 211–218, Dec. 2010, doi: 10.1016/j.jsb.2010.06.021.

[6] K. Dabov, A. Foi, V. Katkovnik, and K. Egiazarian, "Image Denoising by Sparse 3-D Transform-Domain Collaborative Filtering," *IEEE Trans. Image Process.*, vol. 16, no. 8, pp. 2080–2095, Aug. 2007, doi: 10.1109/TIP.2007.901238.