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Model-based Iterative Reconstruction for Low-dose Electron Tomography

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Bright-field TEM tomography of biological specimens typically requires low electron dosages in order to prevent sample degradation [1]. Reconstruction of low-dose tomography is challenging due to the inability of standard tomographic reconstruction algorithms like filtered back projection (FBP) to handle low signal-to-noise ratio data sets. Furthermore, the limited tilt angles associated with the data result in significant missing wedge artifacts with the conventional methods. Model-based iterative reconstruction (MBIR) algorithms have been shown to significantly improve the quality of reconstructions for High Angle Annular Dark-Field STEM tomography [2], and they have also enabled significant dosage reductions in medical tomography [3] while preserving the quality of reconstructions. MBIR includes an explicit model for the physics of image formation with a noise model for the detector, and a model for the unknown sample, while formulating the reconstruction as minimizing a cost function.

Here we present a MBIR method for low-dose bright-field electron tomography. We combine a Beer's law model for electron transmission with the Poisson statistics of the detector and a Markov random field model for the sample to formulate the MBIR cost function. We then develop a fast iterative algorithm to minimize the cost. The algorithm automatically initializes various parameters for the cost function based on the input data set thereby making the algorithm easily usable across a wide range of samples and imaging conditions [4,5].

The effectiveness of the method is demonstrated on polymeric and biological materials that are sensitive to the total exposure dose. Polystyrene-grafted silica nanoparticle hybrids, and horse spleen ferritin (negatively stained with Uranyl Acetate) were deposited on amorphous carbon substrates. Tomographic tilt series were acquired on a C_s (image)-corrected FEI Titan with a dose of 1.3 $e^-/Å^2$ (~10^{-4} C/cm^2) per image, and 75 $e^-/Å^2$ for the total +/- 70° acquisition. This is nominally equal to the maximum dose that would be applied to a cryogenically frozen, unstained sample [1]. Fig.1 shows an image from the ferritin tilt series data at zero tilt. The image is extremely noisy and has a low dynamic range due the low-dosage used. Fig. 2 shows a x-z and x-y cross section from the FBP and MBIR reconstruction. Observe that the MBIR reconstructions clearly show the iron oxide (ferrihydrite) cores and the negatively stained protein cage of the ferritin protein, while the FBP has strong streak artifacts as well as noise in the reconstructions. Fig. 3 shows a low dose acquisition from polystyrene-grafted silica nanoparticles. Again, the MBIR reconstructions in Fig. 4 show decreased noise and artifacts. No pre- or post-reconstruction image processing was applied in either the FBP or the MBIR reconstruction shown here. This suggests that the MBIR approach can be very useful for low-dose tomography.

References

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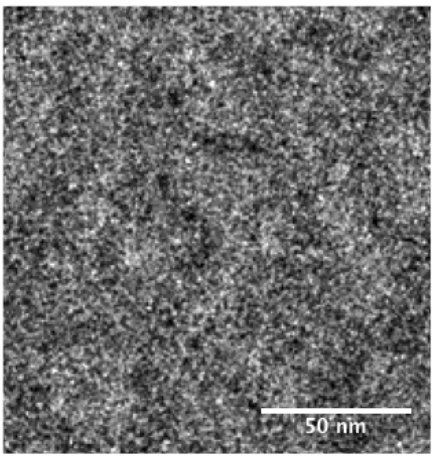

Fig.1 Low dose TEM image of ferritin data when the sample is at zero tilt. The data is very noisy and the ferritin is not visible against the substrate.

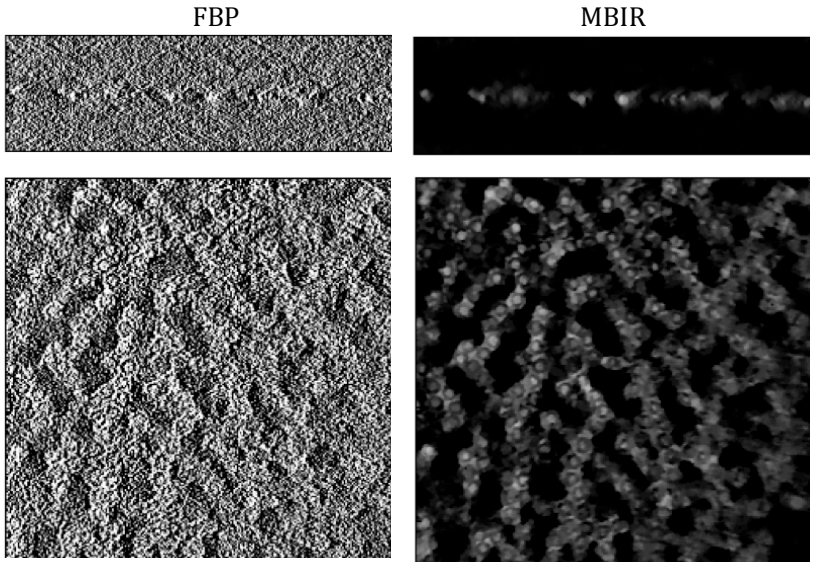

Fig.2 Reconstructed x-z (top row) and x-y (bottom row) cross-sections corresponding to the ferritin data set using FBP and MBIR. The streaks and noise in the FBP reconstructions are completely suppressed by the MBIR reconstruction showing the iron oxide cores and the protein cage.

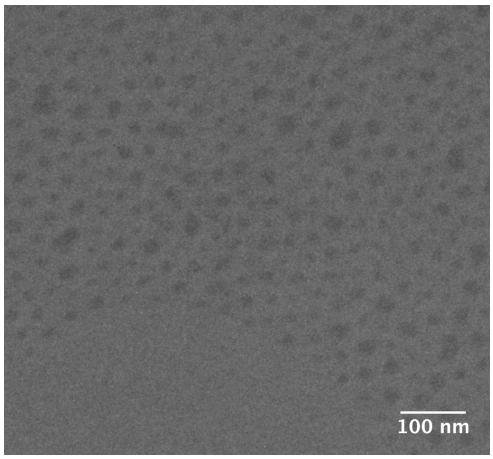

Fig.3 Low-dose TEM image of polystyrene-grafted silica when sample is at zero tilt.

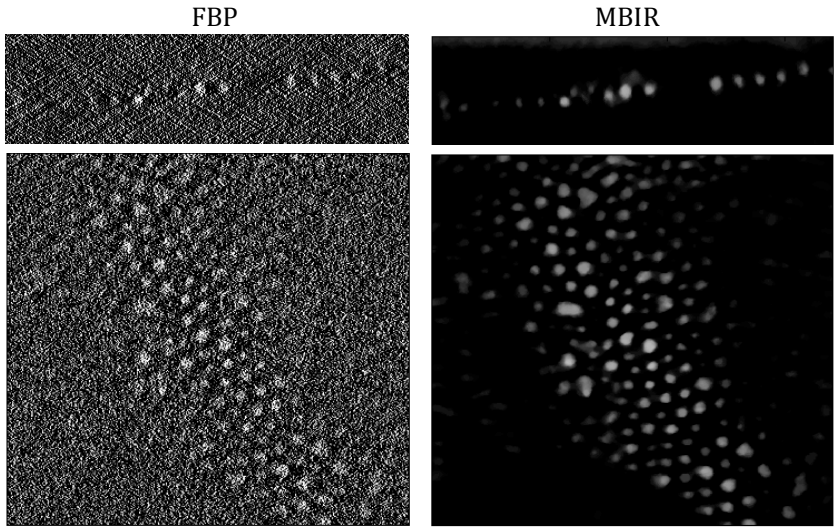

Fig.4 Reconstructed x-z (top row) and x-y (bottom row) cross-sections corresponding to the silica data set using FBP and MBIR. The MBIR reconstructions suppress the artifacts seen in the FBP case.

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