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Library-Based Sparse Interpolation and Super-Resolution of S/TEM Images of Biological and Material Nano-Structures

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Scanning transmission electron microscopes are extensively used for characterization of biological and material samples at the nano-meter scale. However, raster scanning an electron beam across a large field of view is time consuming and can damage the sample. Additionally, in order to form large field of view raster scanned images in a reasonable amount of time, during which the instrument remains at optimal stability, spatial resolution is typically compromised and a standard raster scan size is used (e.g. 2048x2048 or 4094x4096). This leaves significant opportunities for super-resolution and sparse interpolation image reconstruction. For these reasons, there has been a growing need to accurately reconstruct images from sparsely sampled or low-resolution S/TEM images. In many cases, images of biological and material samples contain many structures that are similar or identical to each other. Inspired by the success of modern patch-based denoising filters like non-local means (NLM) in exploiting non-local image redundancies, there have been several efforts to solve the sparse interpolation and super-resolution problems using patch-based models, dictionary learning and example-based methods [1, 2]. In any case, there is no general framework to use any generic denoising algorithm (with or without a patch library) as a prior model to perform sparse interpolation and super-resolution.

In this paper, we introduce a novel algorithm for sparse image interpolation that uses a library of high-resolution image patches to produce an interpolation with appropriate textures and edge features. In addition to reducing mean squared error in the interpolation, our library-based non-local means (LB-NLM) interpolation produces interpolated textures that are visually consistent with the true textures in the S/TEM images. Additionally, the interpolated images lack typical artifacts such as *jaggies* (see Figs. 1 and 2). The key step in our solution is to use the LB-NLM filter as a prior model in our regularized model-based interpolation. To perform this challenging step, we use the plug-and-play (P&P) framework [3] that is based on the alternating direction method of multipliers (ADMM) [4] and decouples the forward model and the prior model terms in the maximum *a* posteriori (MAP) cost function. This results in an algorithm that involves repeated application of two steps: an inversion step only dependent on the forward model, and a denoising step only dependent on the image prior model. The P&P algorithm takes ADMM a step further by replacing the prior model minimization by a denoising operator. Furthermore, the P&P algorithm is shown to converge if the denoising operator has a doubly stochastic gradient [3]. Since LB-NLM weights only the patches from the external library, the gradient of LB-NLM is a diagonal matrix, making it trivially doubly stochastic. Our results demonstrate that using LB-NLM as a prior model within the powerful P&P framework can improve image interpolation quality well beyond linear methods.

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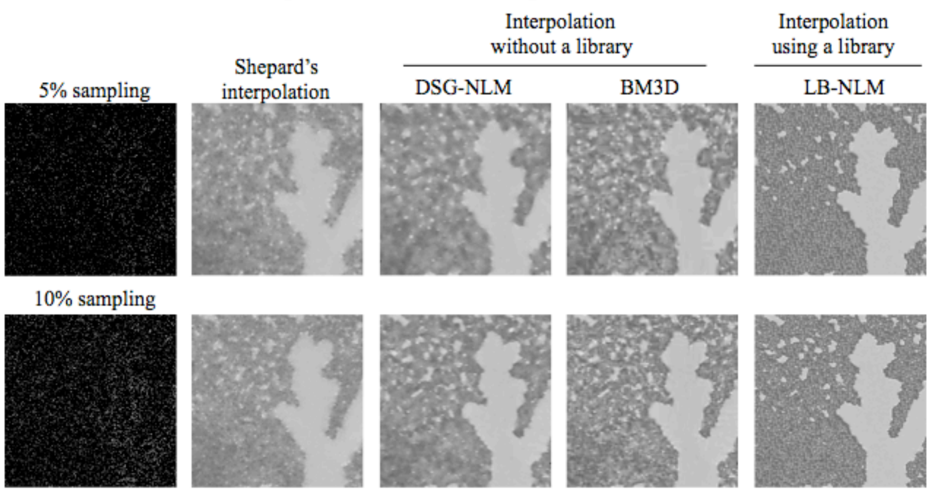

Figure 1. Interpolation of a 256 × 256 TEM image of iridovirus assemblies.

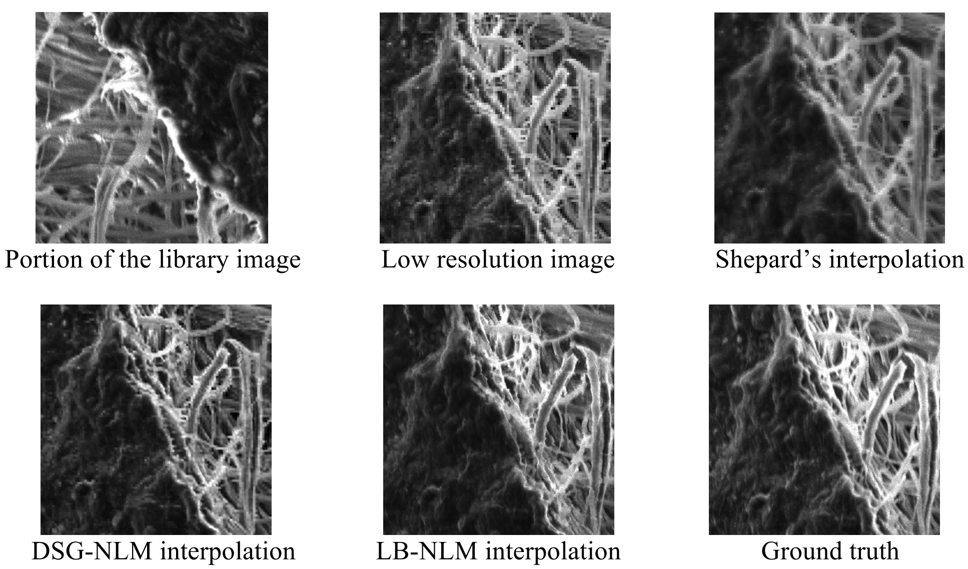

Figure 2. 4x super-resolution of a 100×100 SEM image of surface crack in the shell of the marine mollusk *Hinea brasiliana*.

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