Live Reconstruction of Sparsely Sampled Data for Compressive Sensing and Low-Dose Imaging

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Compressed Sensing (CS) in serial scanning instruments involves sampling a minority fraction (i.e., less than 50%) of the full pixel density while allowing a faithful reconstruction of the object. The benefits of this approach are seen both in a reduction of initial image acquisition time, and a reduction of dose imparted to the sample. Both of these benefits become much more valuable as the sparsity increases. However, the complexity of scanning and image reconstructions also increases at such high sparsity conditions.

A number of requirements must be satisfied to achieve a faithful reconstruction on sparsely sampled data, especially at lower densities. Among these requirements is a high degree of statistical randomness in the sparse sampling strategy. Executing a highly random, high speed, precise scan pattern has been a barrier to these efforts, but by utilizing a novel Compressed Sensing Scan Generator (CSSG) developed in conjunction with PanoScientific we perform scans executing the ideal random patterns that provide the best-case scenario for reconstruction and in painting algorithms.[1]

The computational burden (time) for image reconstructions from sparse data (often also referred to as in-painting), as well as the quality of reconstruction also become increasingly difficult as sparsity increases. Commonly used algorithms for inpainting use methods such as Fourier basis and dictionary-based machine learning and achieve varying degrees of success, but the methods with the best reconstructions are often slow iterative processes, taking minutes or even hours for larger images. When an operator is present at an instrument making sparse observations, it is useful to have some form of live feedback in real time. We present an "Adaptive Real Time In-painting" algorithm (ARTI) to support the CSSG user with live (faster than acquisition time) feedback during sparse scans (a) and compare its performance (d) to other methods (b,c).

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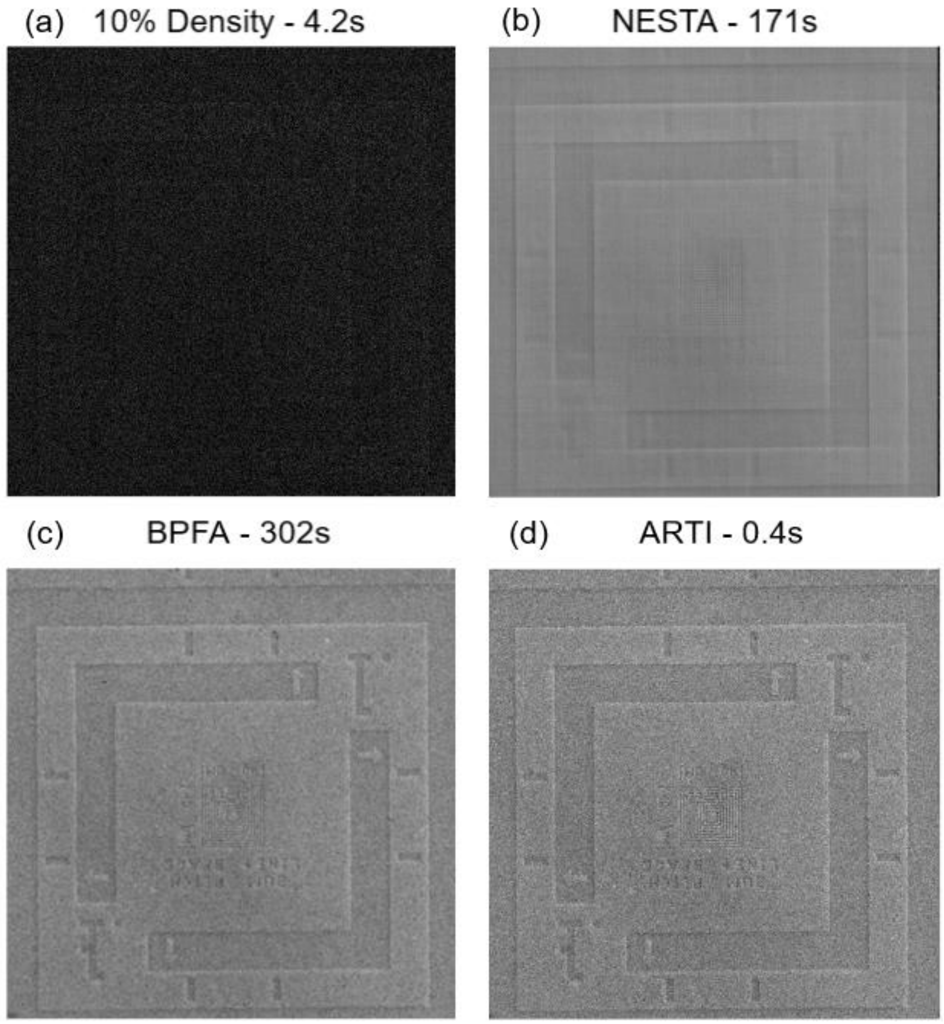

Top Left: 10% Density (90% Sparsity) SEM Scan of a Geller Resolution Standard acquired using the CSSG (Compressed Sensing Scan Generator) connected to the standard external scan interface of a scanning electron microscope.

Top Right: Reconstruction using NESTA[2] showing artifacts introduced in the form of horizontal and vertical lines across the image

Bottom Left: Reconstruction using a variation of the BPFA[3] method widely used in compressive sensing. This variation has been highly optimized for speed. Offers good reconstruction but due to the nature of the method is slow for large images.

Bottom Right: Reconstruction using ARTI (Adaptive Real Time In-painting) produces images comparable to BPFA but in real time offering the user instant feedback when operating an instrument in a sparse scanning mode.

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[2] NESTA: A Fast and Accurate First-Order Method for Sparse Recovery", SIAM Journal on Imaging Sciences, 4, 1, January 2011 [BBC11]

[3] A. Stevens, et al.: "Sub-sampled Approaches for Extremely Low-Dose Scanning Transmission Electron Microscopy," Applied Physics Letters, 2018, 112, p. 043104.