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Realtime Up-sampling Noise Filter: Paradigm Shift for Data Acquisition

Akimitsu Ishizuka[1], Koji Kimoto[2] and Kazuo Ishizuka[1]

[1]HREM Research Inc., Higashimatsuyama, Saitama, Japan, [2]National Institute for Materials Science, Tsukuba, Ibaraki, Japan

In microscopy, image quality is usually judged by visual inspection, and the images should be smooth and high contrast. For this reason, data acquisition is often performed at a high-magnification to get the images that are smooth and look beautiful. However, such image data is usually oversampled. In other words, the pixel size in TEM is smaller than necessity, and the sampling interval in STEM is narrower than prerequisite. This becomes apparent when the image data is subjected to Fourier transform. Here, there is no high-frequency component except from noise, and the signal intensity appears only in the central region of the Fourier transform. According to the sampling theorem, the image information is retained even if the signal intensity has spread to the full range of the Fourier transform. Nevertheless, the data acquired with such optimal sampling is not attractive for a human operator.

If the data is obtained by satisfying the sampling theorem, however, a smooth image can be simply obtained by up-sampling with Fourier transform. We may note that up-sampling and noise reduction can be performed simultaneously through Fourier transform. This technique has been implemented as a new functionality of HREM-Filters Pro [1], a plug-in for DigitalMicrograph. Furthermore, if the image size is moderate, for example, 512 x 512, the new up-sampling noise filter works in live. Using this live filter, the operator can align the microscope and set up experimental conditions while looking at the noise-reduced up-sampled image. In addition, the live up-sampling noise filter is effective for low dose observation, since it will help an operator to inspect a sample. Alternatively, if this up-sampling technique is used, a wider field of view can be observed using the same camera. For example, you can obtain an image that is equivalent to 4kx4k pixels using a 2kx2k camera.

Figure 1 sows an example of the up-sampling noise filter. A series of low dose STEM images (256x256 pixel) of single-layer graphene taken at 80kV, where an average signal corresponds to only 1.6 el/pix/frame. A single frame of the common area after an off-line drift correction is shown in (a). Its Fourier transform indicates that this data is over-sampled more than by 4. (b) shows the image down-sampled by 4, and its Fourier transform. (c) is an image obtained by accumulating all 300 frames, which clearly shows the model structure. (d) is a noise filtered image of (a), while (e) is a noise filtered image of (b) up-sampled by 4, where the latter is almost identical to the former. It may be stressed that both the noise filtered images, (d and e), of *single* frame are comparable with the accumulated image (c).

Figure 2 illustrates noise filtering of low dose TEM images of MOF taken at 300kV [2]. (a) shows an area of 2kx2k pixels acquired with a Gatan K2 camera working at Electron Counting mode, while (b) an enlarged part of the ROI (512x512), where consecutive ten frames are accumulated to reveal the sample feature. The histogram in (a) indicates the low dose rate of 0.25 el/pix/frame. The noise filtered image (c) is obtained from the inset image in (a) that corresponds to a *single* frame at the same area indicated by the ROI. It may be noteworthy that the noise filtered image (c) of the single frame is better than the accumulated image over 10 frames (b), although the raw single frame does not reveal any feature.

A recent trend of data acquisition is a live drift correction to accumulate the frames obtained with a short exposure. However, it is not a good idea to accumulate many frames from a beam sensitive sample. In this

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report, we have demonstrated that the real-time up-sampling noise filter can reveal the sample structure even from a *single* frame and help to perform experiments. Then, the real-time noise filter and off-line non-rigid alignment [3] is a better strategy of data acquisition than the live drift correction. The real-time up-sampling noise filter will require a drastic reassessment of existing data collection scheme.

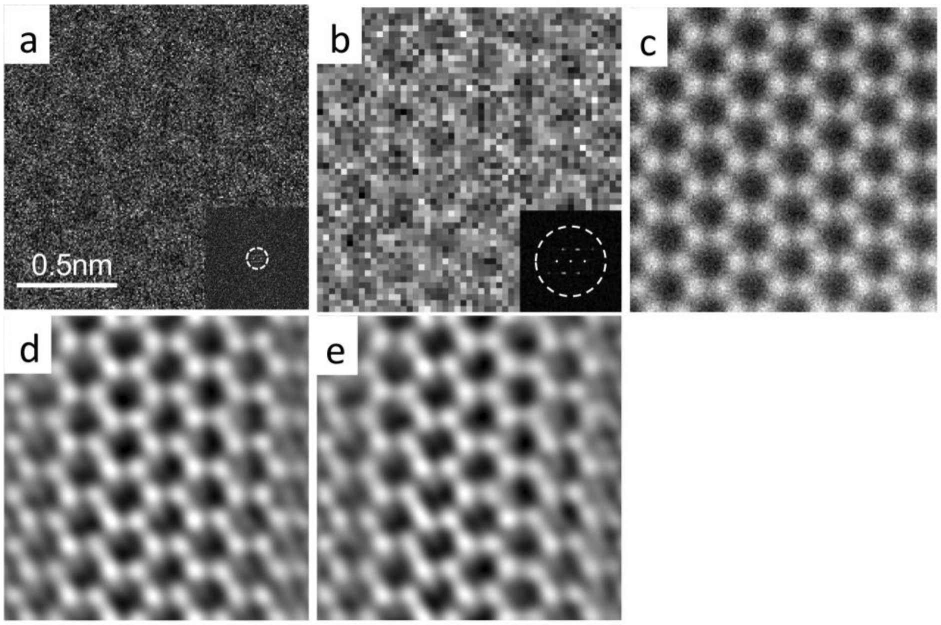

Figure 1. Up-sampling noise filter. (a) a single frame of single-layer graphene and its Fourier transform. (b) an image binned by 4 from (a) and its Fourier transform. (c) a 300-accumulated image. (d) a noise filtered image of (a). (e) a 4-time up-sampled noise filtered image of (b).

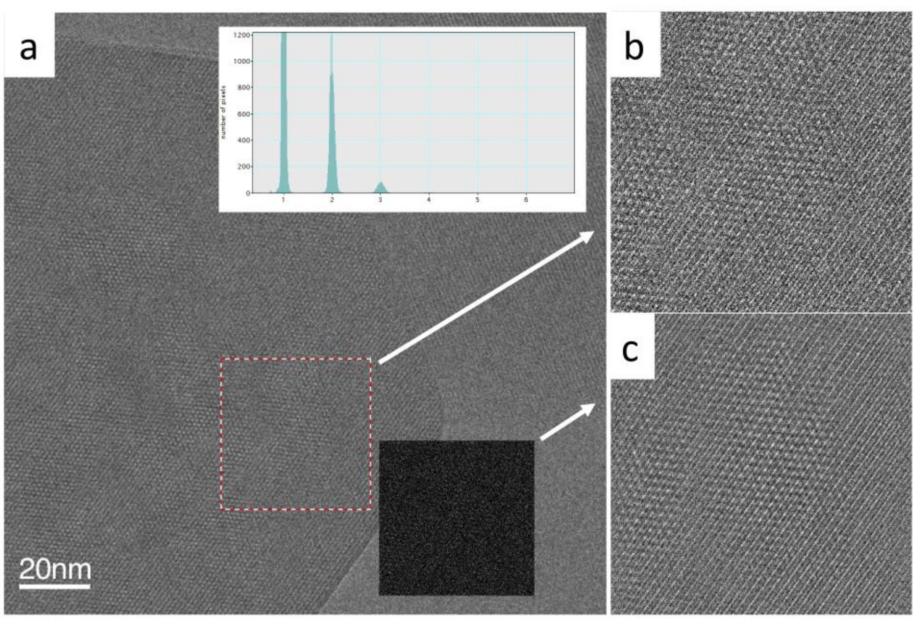

Figure 2. Noise filtering for low-dose images of MOF [2]. (a) an image (2kx2k image) accumulated over ten frames to reveal the sample. Inset histogram corresponds to a single frame. (b) an enlarged part of the accumulated image. (c) a noise filtered image from the same area of the single frame.

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References

[1] HREM-Filters Pro: https://www.hremresearch.com/Eng/plugin/FiltersEng.html
[2] Data courtesy of Xiaoxiao Cao, Gatan China.
[3] SmartAlign: https://www.hremresearch.com/Eng/plugin/SmartAlignEng.html.

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