# Online Beam Current Estimation in Particle Beam Microscopy Through Time-Resolved Measurement

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Conventional particle beam microscopy requires knowledge of the beam current for accurate micrograph formation and sample milling. In practice, beam current fluctuations while the sample is horizontally raster scanned give rise to horizontal stripe artifacts in the micrograph, as shown for a synthetic SEM scenario in Figure 1(b). Existing mitigation techniques apply image processing tools to remove striped content post facto[1] (ex. Figure 1(c)) and may also remove true features of the underlying image. Time-resolved (TR) measurement, which divides the dwell time into $n$ shorter sub-acquisitions, can be implemented without changes to the instrument and has enabled reconstruction techniques that mitigate the effects of source shot noise.[2] These techniques (Figure 1(d)) are naturally more robust to imperfect knowledge of the beam current.[3] In this work we establish that beam current can be explicitly estimated *online* from time-resolved data, without the use of a calibrated sample. Our method prevents artifacts in the micrograph and provides the operator with novel information about instrument fitness.[4]

In Figure 1, we show our reconstruction results without (e) and with (f) total variation regularization of the micrograph. Both estimates have lower root-mean square error (RMSE) than the state-of-the-art mitigation technique. Figure 2 demonstrates that our beam current estimate is a close match to the true beam current. This estimate could be used to determine milling time or for feedback control of the current itself.

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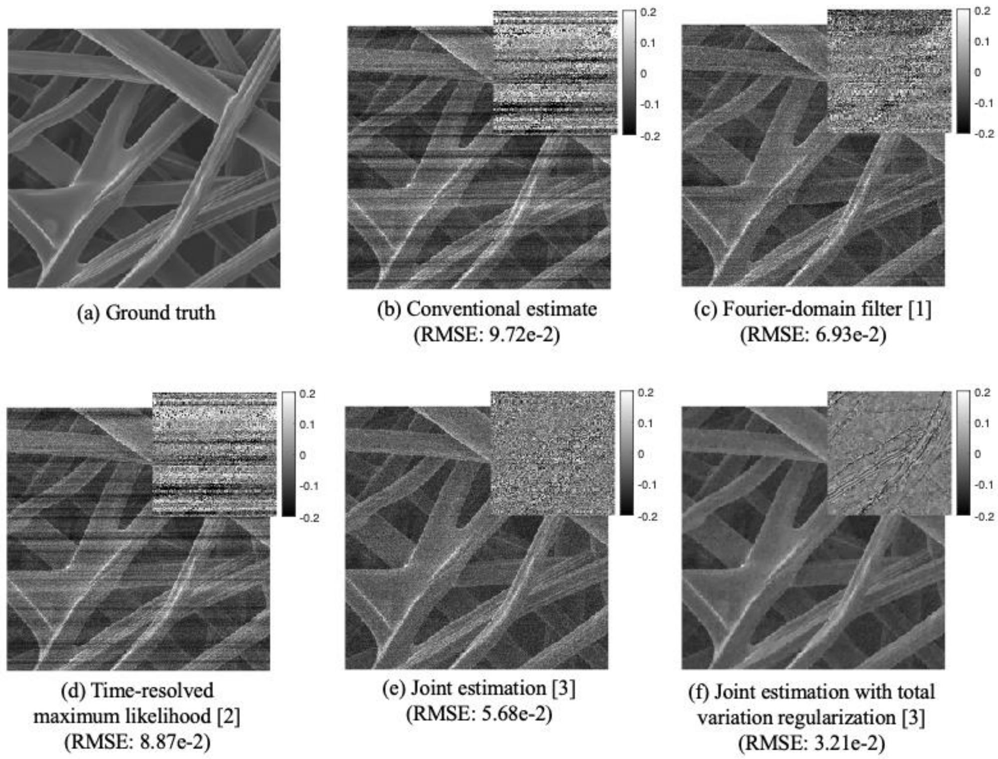


(a) Ground truth

(b) Conventional estimate (RMSE: 9.72e-2)

(c) Fourier-domain filter [1] (RMSE: 6.93e-2)

(d) Time-resolved maximum likelihood [2] (RMSE: 8.87e-2)

(e) Joint estimation [3] (RMSE: 5.68e-2)

(f) Joint estimation with total variation regularization [3] (RMSE: 3.21e-2)

*Figure 1: Synthetic Microscopy Results:* Estimation algorithms assume a mean dose of $\bar{\lambda} = 200$ incident particles per pixel, although the actual dose is a Gaussian autoregressive random process with standard deviation $\sigma_\lambda = 40$. The nominal dose per sub-acquisition is 0.1 particles. Inset plots show the error between estimates and ground truth for a small image patch. Root-mean-square error (RMSE) is used as an error metric. Ground truth image taken from the Thermo Fisher Scientific microscopy image database scaled to secondary electron yield in $[0.2, 1]$.

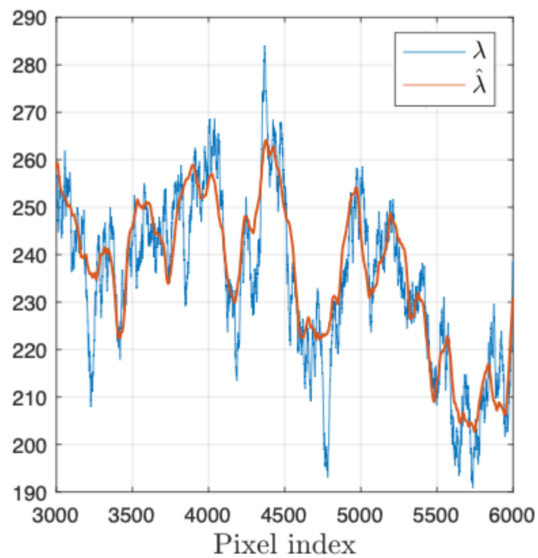


*Figure 2:* Beam current estimate $\hat{\lambda}$, in units of incident particles corresponding to the estimate in Figure 1(c). Estimate RMSE = 6.6761.