

P11 – Quantifying and Pinpointing Sources of Noise in Optical Tweezers Experiments

Fabian Czerwinski¹⁾²⁾, Ulrich F. Keyser²⁾, and Lene B. Oddershede¹⁾


¹⁾Niels Bohr Institute, University of Copenhagen,
Copenhagen, Denmark

²⁾Cavendish Laboratory, BSS, University of Cambridge,
Cambridge, United Kingdom

Optical trapping techniques have evolved to the point where quantitative force measurements on biological systems can be performed down into the femtonewton range. As resolution is constantly improving, the pinpointing and elimination of noise sources become increasingly important. Allan-variance analysis is ideally suited for this task; adjacent time series are recorded and the variations between observation intervals are calculated [1].

Here, we provide a comprehensive toolbox consisting of: a reliable data-streaming acquisition software that allows for streaming long adjacent time series (~30min), even with high sampling frequencies (>80kHz); an analysis software (Matlab-based) with calculation times of only a few seconds; and fitting scripts to extract parameters of noise and drift sources. Furthermore, the validity and robustness of Allan-variance analysis is demonstrated in data obtained from our optical-tweezers setup wherein laboratory-specific noise sources are detected. In addition, a detailed Allan-variance analysis clarifies the difference between two common detection systems, a quadrant photodiode and a position-sensitive photodiode [2, 3]. Lastly, we demonstrate how our toolbox can be applied to position-time traces of optically trapped spheres to determine the optimal calibration interval for any setup, suitable settings for variance and update rates in force-feedback loops, and variations due to the geometrical constraints of the sample chamber [4]. Allan-variance analysis can be used as a standard tool enabling reliable comparison of different optical-tweezers setups and the precise quantification of noise and drift sources, which are particularly relevant in high precision experiments with individual biomolecules.

- [1] G.M. Gibson, J. Leach, S. Keen, A.J. Wright, and M.J. Padgett, "Measuring the Accuracy of Particle Position and Force in Optical Tweezers Using High-Speed Video Microscopy," *Opt. Express* 16, 14561-14570 (2009)
- [2] F. Czerwinski, A.C. Richardson, and L.B. Oddershede, "Quantifying Noise in Optical Tweezers by Allan Variance," *Opt. Express* 17, 13255-13269 (2009)
- [3] F. Czerwinski, "allan v1.71," *MatlabCentral* 21727, 2008
- [4] F. Czerwinski, A.C. Richardson, C. Selhuber-Unkel, and L.B. Oddershede, "Allan Variance Analysis as Useful Tool to Determine Noise in Various Single-Molecule Setups," *Proc. SPIE*, Vol. 7400, 740004 (2009)




Cavendish Laboratory
UNIVERSITY OF CAMBRIDGE

czerwinski@nbi.dk

Quantifying and Pinpointing Sources of Noise in Optical Tweezers Experiments

Fabian Czerwinski^{1,2}, Ulrich F. Keyser², Lene B. Oddershede¹

¹Niels Bohr Institute, University of Copenhagen, Denmark
²Cavendish Laboratory, BSS, University of Cambridge, United Kingdom



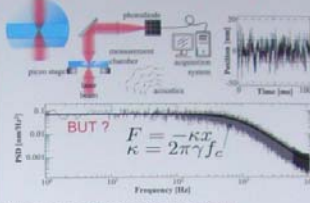
Motivation: Very-Low Frequency Drift

Optical-trapping techniques have evolved to the point where quantitative force measurements on biological systems can be performed down into the femtonewton range. As resolution is constantly improving, the pinpointing and elimination of noise sources become increasingly important. Allan-variance analysis is ideally suited for this task.

We provide a toolbox of reliable data-streaming acquisition software as well as analysis software (Matlab-based) with calculation times of only a few seconds. It particularly allows for the quantification of very-low frequency drift.

Allan-variance analysis can be used as a standard tool enabling reliable comparison of different optical-tweezers setups and the precise quantification of noise and drift sources, which are particularly relevant in high precision experiments with individual biomolecules.

Calibrate Optical Tweezers and Quantify High-Frequency Noise



Calibration: assume harmonic potential, corner frequency proportional to trap stiffness
Noise spectrum at high frequencies: aliasing, filtering...

Allan Variance

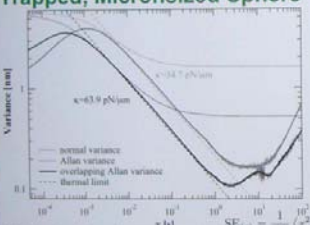
converges to finite value for most "biophysical noise": white noise, shot noise, damped oscillations, ...

$$\sigma_x^2(\tau) = \frac{1}{2} \langle (\Delta x)^2 \rangle_\tau$$

requirements: long adjacent time series of reliable data

code on allan v1.71, MatlabCentral 21727, 2008

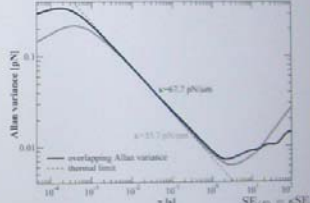
Allan Variance of an Optically Trapped, Micronized Sphere



Drift dominant beyond measurement times of a few seconds; transition marks optimal calibration interval

thermal limit $\approx \sqrt{\frac{2k_B T \gamma}{\kappa}}$

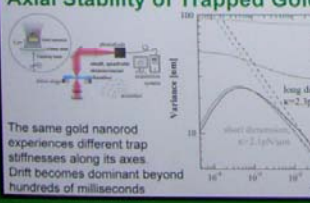
Force Sensitivity

$$\sigma_F^2(\tau) = \frac{1}{2} \langle (\Delta F)^2 \rangle_\tau = \frac{1}{2} \langle (\kappa \Delta x)^2 \rangle_\tau = \kappa^2 \sigma_x^2(\tau)$$


Weaker traps provide a higher force sensitivity

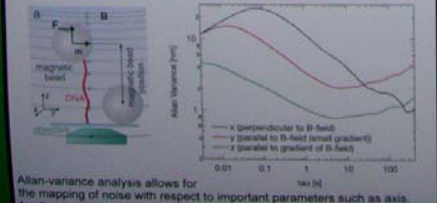
thermal limit $\approx \sqrt{\frac{2k_B T \gamma}{\kappa}}$

Axial Stability of Trapped Gold Nanorods



The same gold nanorod experiences different trap stiffnesses along its axes. Drift becomes dominant beyond hundreds of milliseconds

Allan Variance for Magnetic Tweezers

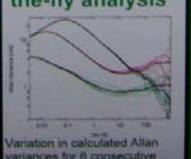


Allan-variance analysis allows for the mapping of noise with respect to important parameters such as axis, feedbacks, DNA contour length and degrees of supercoiling

References

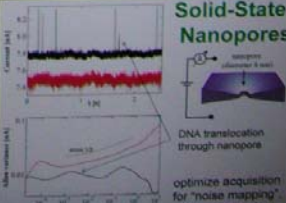
- Czerwinski, Richardson, Oddershede: *Quantifying Noise in Optical Tweezers*. Optics Express 17:13255-13269, 2009
- Gibson, Leach, Keen, Wright, Padgett: *Measuring the Accuracy of Particle Position and Force in Optical Tweezers using High-Speed Video Microscopy*. Optics Express 16:14561-14570, 2008
- Czerwinski et al.: *Allan Variance Analysis as Useful Tool to Determine Noise in Various Single-Molecule Setups*. Proc SPIE, 740004, 2009
- Czerwinski: *allan v1.71*, MatlabCentral 21727, 2008.
<http://www.mathworks.com/matlabcentral/fileexchange/21727>

Reliability of on-the-fly analysis



Variation in calculated Allan variances for δ consecutive measurements

Solid-State Nanopores



optimize acquisition for "noise mapping" DNA translocation.

We thank Ralf Seidel, Daniel Klaue and Derek Stein for experiments on magnetic tweezers and solid-state nanopores

Scanning Probe Microscopy & Optical Tweezers in Life Sciences – 14/15 October 2009 in Berlin
www.nanobioviews.net

2/2