Toward Consistent and Reproducible Tip-Sample Force Reconstruction in Dynamic Atomic Force Microscopy

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Dynamic modes of atomic force microscopy (AFM) are widely used to probe tip-sample interaction force with unprecedented precision, with piconewton force and picometer spatial resolution. Nevertheless, the forces are not directly accessible and must be inferred from observables such as amplitude, phase, or resonance frequency shift. Over the past two decades, numerous force reconstruction methods have been developed, each grounded in distinct theoretical assumptions and applied under varying experimental conditions [1-13]. This diversity has led to inconsistencies in interpretation across studies. In this work, we present a comprehensive evaluation of the most commonly used force reconstruction techniques in both frequency- and amplitude-modulation AFM. We analyze their mathematical foundations, outline their domains of applicability, and quantify their performance using theoretical and experimental data [14]. To facilitate transparent benchmarking and widespread adoption, we introduce an open-source software framework that integrates all major reconstruction approaches, providing a unified platform for comparison and application. Our results highlight key trade-offs and common pitfalls, offering practical guidance for researchers seeking accurate and interpretable force measurements. This effort lays the groundwork for more robust and reproducible dynamic AFM force spectroscopy across disciplines.

References:

1. Giessibl, F.J., Physical Review B, 1997. **56**(24): p. 16010-16015.
2. Hölscher, H., U.D. Schwarz, and R. Wiesendanger, Applied Surface Science, 1999. **140**(3): p. 344-351.
3. Hölscher, H., et al.,. Physical Review Letters, 1999. **83**(23): p. 4780-4783.
4. Dürig, U., Applied Physics Letters, 1999. **75**(3): p. 433-435.
5. Giessibl, F.J., Applied Physics Letters, 2001. **78**(1): p. 123-125.
6. Sader, J.E. and S.P. Jarvis, Applied Physics Letters, 2004. **84**(10): p. 1801-1803.
7. Lee, M. and W. Jhe, Physical Review Letters, 2006. **97**(3): p. 036104.
8. Shuiqing, H. and R. Arvind, Nanotechnology, 2008. **19**(37): p. 375704.
9. J. Katan, A., M. H. van Es, and T. H. Oosterkamp, Nanotechnology, 2009. **20**(16): p. 165703.
10. Amir, F.P., M.-J. Daniel, and G. Ricardo, Nanotechnology, 2015. **26**(18): p. 185706.
11. Dagdeviren, O.E., Review of Scientific Instruments, 2021. **92**(6): p. 063703.
12. Sader, J.E., et al., Nature Nanotechnology, 2018. **13**(12): p. 1088-1091.
13. Dagdeviren, O.E., et al., Physical Review Applied, 2018. **9**(4): p. 044040.
14. Laflamme, S., Guner B., Dagdeviren O.E., arXiv:2506.06467.

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