Uncertainty quantification and estimation in differential dynamic microscopy

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What was achieved?: A statistical analysis that reduces computational times by 25-120 times in Differential Dynamic Microscopy (DDM), was achieved. DDM is a technique that exploits optical microscopy to obtain local, multi-scale quantitative information about dynamic samples, such as liquid suspensions, soft materials, cells, and tissues. In DDM, image sequences are analyzed via a combination of image differences and spatial Fourier transforms to obtain information such as the dynamic structure function which elucidates inter-particle correlations and their time evolution. It was shown that the prediction of the image structure function requires only around 0.5%–5% of the Fourier transforms of the observed quantities. The approach, named DDM with uncertainty quantification (DDM-UQ), was validated using both simulations and experiments with respect to accuracy and computational efficiency, as compared with conventional DDM and multiple particle tracking.

Why is it important?: Despite DDM's broad usefulness in determining dynamical properties, it has not been fully adopted as a routine characterization tool, largely due to computational cost and lack of algorithmic robustness. DDM-UQ quantifies the noise, reduces the computational order and enhances the robustness of DDM analysis, laying the foundation for important new applications of DDM, as well as to high-throughput characterization. Moreover, with the potential to carry out real-time analysis via down-sampling, the proposed method can be extended to map out an entire phase space of material composition or physicochemical conditions in a high-throughput manner. DDM-UQ-powered software package will significantly improve the performance of BioPACIFIC MIP's micro-rheology tool and will become available to all its users as well as for any non-profit use.

How did BioPACIFIC MIP enable this?: By providing financial support for one female postdoctoral scholar and one female graduate student through the Fellows program, as well as funds for the materials and development of a state-of-the-art DDM-based high-throughput micro-rheometer.
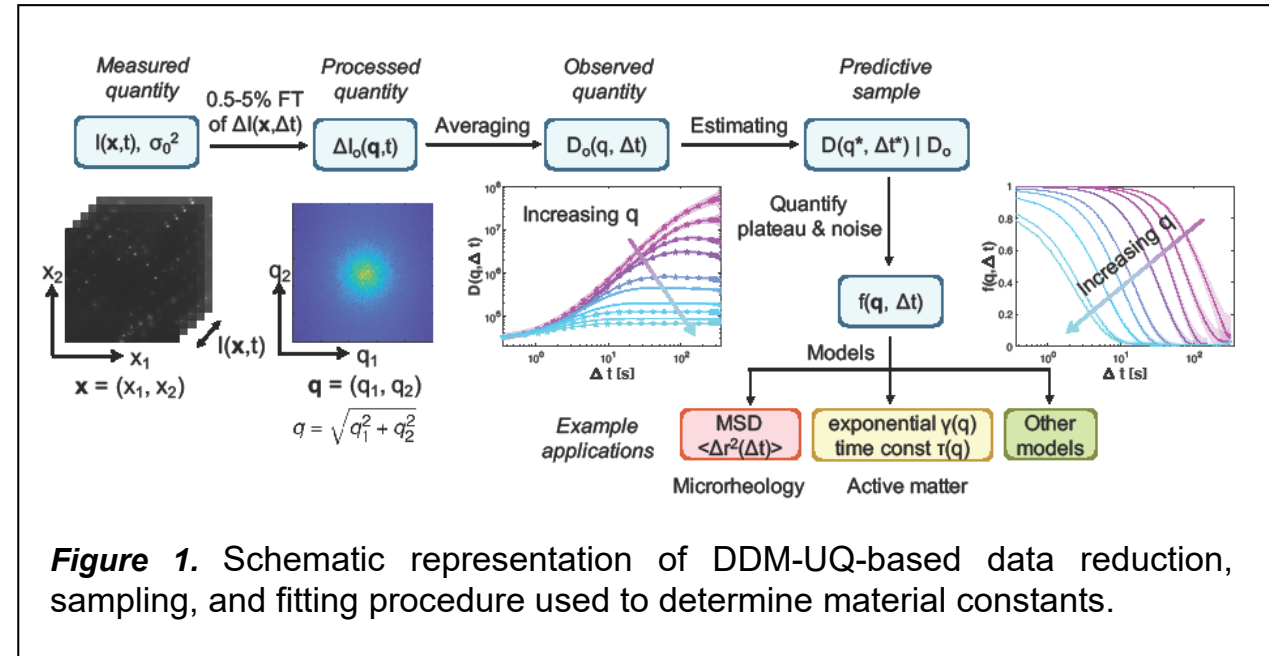

Figure 1. Schematic representation of DDM-UQ-based data reduction, sampling, and fitting procedure used to determine material constants.

- Gu, M., Luo, Y., He, Y., Helgeson, M. E., & Valentine, M. T. Uncertainty quantification and estimation in differential dynamic microscopy. *Physical Review E*, **104**, 034610, 2021.
- The MATLAB package is available at: https://github.com/UncertaintyQuantification/DDM-UQ.

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