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Thesis abstract

Self-sensing, estimation and control in multifrequency Atomic Force Microscopy

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Despite the undeniable success of the atomic force microscope (AFM), dynamic techniques still face limitations in terms of spatial resolution, imaging speed and high cost of acquisition. In order to expand the capabilities of the instrument, it was realized that the information about the nano-mechanical properties of a sample are encoded over a range of frequencies and the excitation and detection of higher-order eigenmodes of the micro-cantilever open up further information channels. The ability to control these modes and their fast responses to excitation is believed to be the key to unravelling the true potential of these methods. This work addresses three major drawbacks of the standard AFM setup, which limit the feasibility of multi-frequency approaches.

First, microelectromechanical system (MEMS) probes with integrated piezoelectric layers is motivated, enabling the development of novel multimode self-sensing and self-actuating techniques. Specifically, these piezoelectric transduction schemes permit the miniaturization of the entire AFM towards a cost-effective single-chip device with nanoscale precision in a much smaller form factor than that of conventional macroscale instruments.

Second, the integrated actuation enables the development of multimode controllers which exhibits remarkable performance in arbitrarily modifying the quality factor of multiple eigenmodes and comes with inherent stability robustness. The experimental results demonstrate improved imaging stability, higher scan speeds and adjustable contrast when mapping nano-mechanical properties of soft samples.

Last, in light of the demand for constantly increasing imaging speeds while providing multi-frequency flexibility, the estimation of multiple components of the high-frequency deflection signal is performed with a linear time-varying multi-frequency Kalman filter. The chosen representation allows for an efficient high-bandwidth implementation on a Field Programmable Gate Array. Tracking bandwidth, noise performance and trimodal AFM imaging on a two-component polymer sample are verified and shown to be superior to that of the commonly used lock-in amplifier.

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