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Model-Based Identification of Nanomechanical Properties in Atomic Force Microscopy

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Outline

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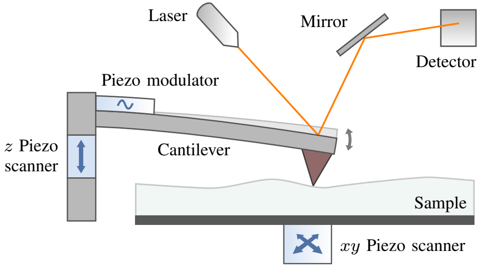
Introduction

— Atomic force microscopy (AFM) is capable of measuring forces into the piconewton range.



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  to relate the observables to mechanical properties.
- In our work, we propose a method to relate the nanomechanical properties directly from the observables using the time-domain dynamic models.

Overview of proposed method

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— Combine the cantilever and sample model.

— Use parameter identification techniques to relate the observables to sample parameters.

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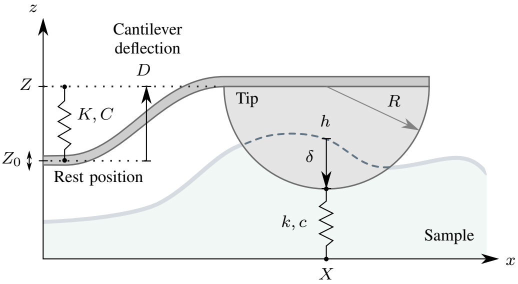
Cantilever dynamics

Approximation by first resonance mode.

$$M\ddot{D} + KD + C\dot{D} = F_{\text{mod}} + F_{\text{ts}}. \quad (1)$$



Contact model

Modified Hertz contact model.

$$F_{\text{ts}} = E'\delta^{\frac{3}{2}} + c\dot{\delta} \tag{2}$$

$$E = \frac{3}{4}R^{-\frac{1}{2}}(1-\nu^2)E' \tag{3}$$

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Parametric model

Combining the previous cantilever and sample models gives the system

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and rewrite (4) as

$$w' = \begin{bmatrix} c \\ E' \end{bmatrix}^T \begin{bmatrix} s\delta \\ \delta^{1.5} \end{bmatrix} \tag{6}$$

$$= \boldsymbol{\theta}^T \boldsymbol{\phi}' \tag{7}$$

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Persistently exciting $\phi \rightarrow$ exponential convergence of parameters.

Parameter estimator

Least squares method with forgetting factor (Ioannou and Sun 1996).

$$\widehat{w} = \widehat{\boldsymbol{\theta}}^T \boldsymbol{\phi} \quad (8)$$

$$\varepsilon = (w - \widehat{w})/m^2 \quad (9)$$

$$m^2 = 1 + \alpha \boldsymbol{\phi}^T \boldsymbol{\phi} \quad (10)$$

$$\dot{\widehat{\boldsymbol{\theta}}} = \mathbf{P} \varepsilon \boldsymbol{\phi} \quad (11)$$

$$\dot{\mathbf{P}} = \beta \mathbf{P} - \mathbf{P} \frac{\boldsymbol{\phi} \boldsymbol{\phi}^T}{m^2} \mathbf{P} \quad (12)$$

$$\mathbf{P}(0) = \mathbf{P}_0 \quad (13)$$

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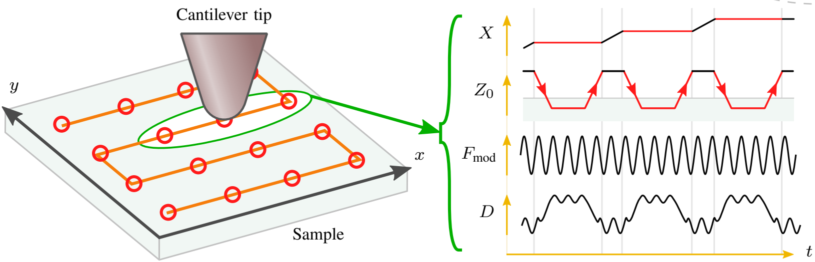
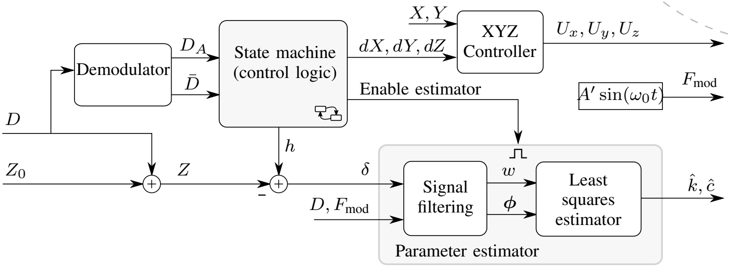
Procedure



Experimental setup

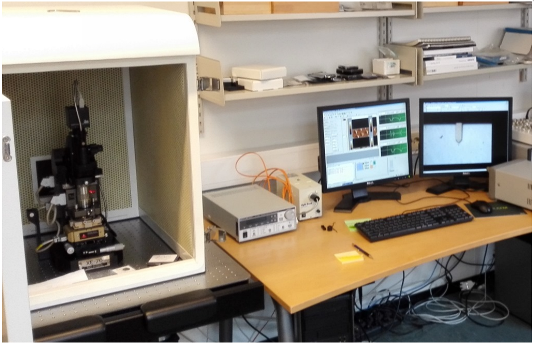


Block diagram of the control logic and parameter estimator.

Experimental setup

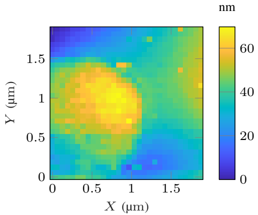
- Implemented on a commercial AFM, Park Systems XE-70.
- All aspects controlled by our own algorithms.
- Real-time implementation at 200 kHz on a dSpace computer.
- Spherical carbon tip cantilever, radius 40 nm (B40_CONTR).
- Cantiler parameters M, K, C determined a priori.

Experimental setup

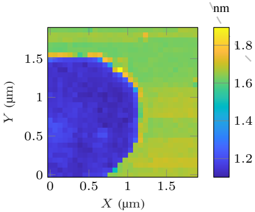


Park Systems XE-70 AFM and setup.

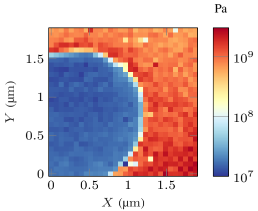
Experimental results: Two-component polymer sample



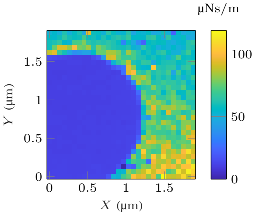
(a) Topography



(b) Amplitude

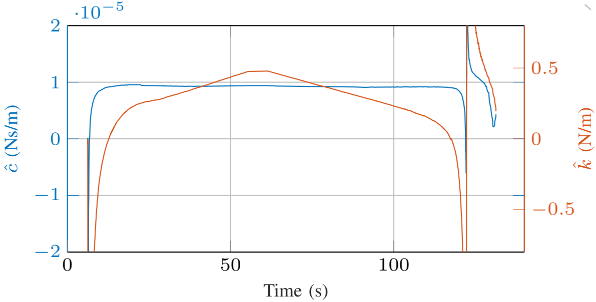


(c) Elastic modulus



(d) Damping coefficient

Experimental results: Time-varying parameters



Time-varying sample parameter estimates during indentation.

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Conclusion

— Online, model-based identification technique for nanomechanical properties.
— Sample parameters are mapped from observables in a least squares sense.
— Handles nonlinear force interactions naturally.
— Time-domain approach, circumvents the need
  - for linearization,
  - to consider harmonics,
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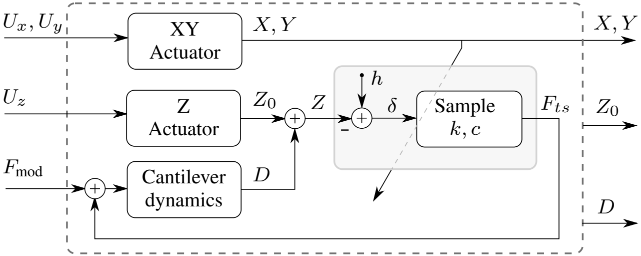
Questions?

Plant dynamics



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