Deconvolution of Atomic Force Measurements in Special Modes – Methodology and Application

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Contents

- SFB 622
- Measurement System / Atomic Force Microscope
- Imaging Model of Kelvin Force Microscopy (KFM)
  - Noise in KFM Data
  - Analytical PSF Estimation
- Model Limitations
- Deconvolution Algorithm
- Deconvolution Results
- Conclusion & Outlook
Goal: Nanopositioning and Nanomeasuring Machine

Positioning volume: 350 mm x 350 mm x 5 - 50 mm
Measurement system: exchangable 2.5D, 3D

Resolution: 0.05 nm
Reproducibility: < 1 nm

Role of supproject C2

Metrological Frame

Primary 3D Features

Interaction Probe / Object from the View of IP

Probes / Tools

User-PC Server

Measured Data Processing

Digital Signal Processor

Data Compression

User-PC

Server

Probes / Tools

Interaction Probe / Object from the View of IP

Primary 3D Features

Metrological Frame

Measurement X

Measurement Z

Mirror

Interaction Probe / Object from the View of IP

Primary 3D Features
Lateral Resolution:

AFM topography mode: approx. 2 nm
AFM special mode: approx. 50 – 100 nm
potential measurement (EFM, KFM),
magnetic force measurement (MFM), ...

Topography measured by AFM

Potential (KFM) measured by AFM
Deconvolution of AFM Measurement in Special Mode

**Imaging process**

- Object
- Disturbed image
- PSF
- Object estimation

**Deconvolution process**

- Inversion PSF
- Disturbed image

- PSF determination
- Noise suppression
Principle: Indirect determination of surface potential by means of an electrostatic force acting on the measuring system

1st pass
Topography determination

2nd pass
Surface potential measurement

\[ F_{c,o}(x, y) = \int \int C''(x, y) \cdot (\Phi(x, y) - \Phi_t) \cdot U_{ac} \cdot \sin(\omega t) dx dy \]
Imaging Model of KFM

- LSI system: linear shift-invariant system with a point spread function (PSF) as the convolution kernel
- Additive noise at the channel output
Amplitude distribution:
Histogram counting of noise amplitude
⇒ Gaussian distribution
Frequency distribution:
Fourier-transformed KFM image equally distributed ⇒ white noise
Imaging Model of KFM

- Additive white Gaussian noise

\[
\Phi(x,y) \rightarrow \text{LSI system} \rightarrow \Phi_{t}(x,y) + n(x,y) \rightarrow \Phi_{t,n}(x,y)
\]
Image interrelation at KFM

\[ F_{c,\omega}(x, y) = \int\int_{x,y} C'(x, y) \cdot (\Phi(x, y) - \Phi_t) \cdot U_{ac} \cdot \sin(\omega t) \, dx \, dy \]

\[ F_{c,\omega}(x, y) = 0 \quad \text{for} \quad \Phi(x, y) = \Phi_t(x, y) \]

\[ \Phi_t(x, y) = \int\int_{i,j} C'_{ij}(x-x_i, y-y_j) \cdot \Phi(x_i, y_j) \, di \, dj \]

convolution kernel
Transform KFM tip geometry to polar coordinates.

Fit a hyperbola \( r^2 = C_1 z + C_2 z^2 \) to each angle \( \alpha \).

Calculate the electric field distribution at \( \eta = 0 \) and \( \xi \) by means of heights \( C_1 \) and \( C_2 \).
Imaging Model of KFM

- Additive white Gaussian noise
- LSI system: Linear and shift-invariant convolution kernel
Imaging Model of KFM – Model Limitations

Assumptions:

➢ Sample topography must be negligible
➢ Only the electrostatic force is acting on the detection system

Solution:

➢ Measurement at sufficiently large tip-to-sample distance
Inversion of the PSF with Wiener noise subpression

\[ \hat{\Phi} = \frac{OTF^*}{|OTF|^2} \cdot \frac{L_{\Phi_{r,n}}}{L_{\Phi_{r,n}} + \lambda L_{n}} \cdot F\{\Phi_{t,n}\} \]

Wiener filter

inverted OTF
(Optical Transfer Function = Fourier-transformed PSF)

Filter adjustment by resolution boundary
Imaging Model of KFM - Deconvolution

measured KFM data

deconvolved data
KFM measurement data have bad lateral resolution

The imaging process can be described as an LSI model

An analytical method was presented to determine the PSF

Deconvolution was demonstrated using inversion of the PSF and Wiener noise suppression
Using a measured method to determine the PSF

Sample to determine the PSF
(Developed by ZMN Ilmenau, SFB 622 TP A8)

Expansion of the deconvolution method (e.g. pixon method)

Forder practical analysis

BAM-L200
Nanoscale stripe pattern for testing of lateral resolution and calibration of length scale
The End

Thanks for your attention!

Acknowledgement

This work was supported by the German Science Foundation (DFG, SFB 622). The authors wish to thank all those colleagues at the Technische Universität Ilmenau and the ZBS Ilmenau e. V., who have contributed to these developments.