Subpixel Translation of MEMS Measured by Discrete Fourier Transform Analysis of CCD Images

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Outline

Working principle

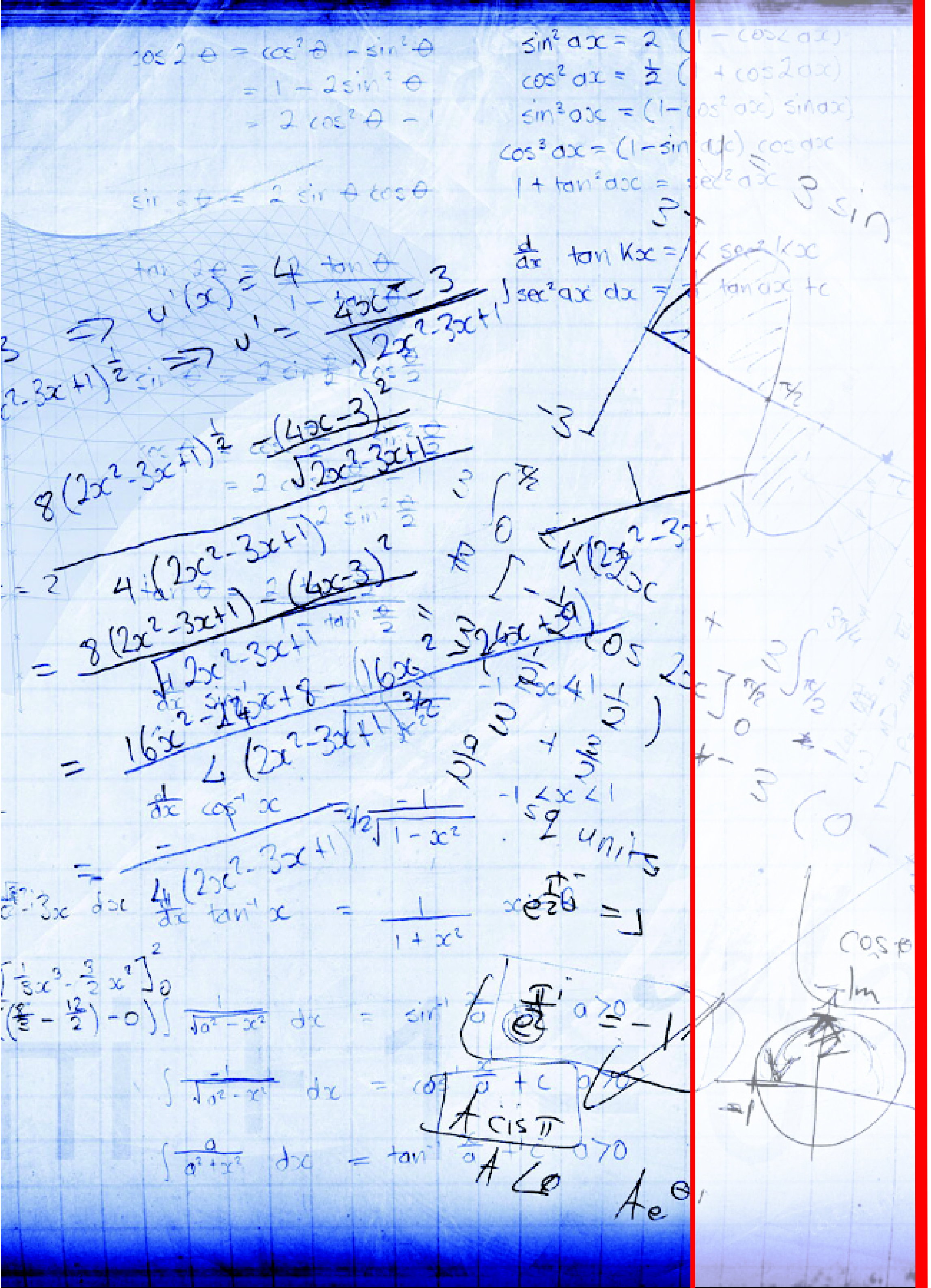
➔ Discrete Fourier Transform applied to image analysis

Computing software

➔ MATLAB Graphical User Interface (GUI)

Experimental results

- Static characterization of MEMS
- Dynamic characterization of MEMS



Working principle

- ➔ Discrete Fourier Transform applied to image analysis

Working principle I Motivation

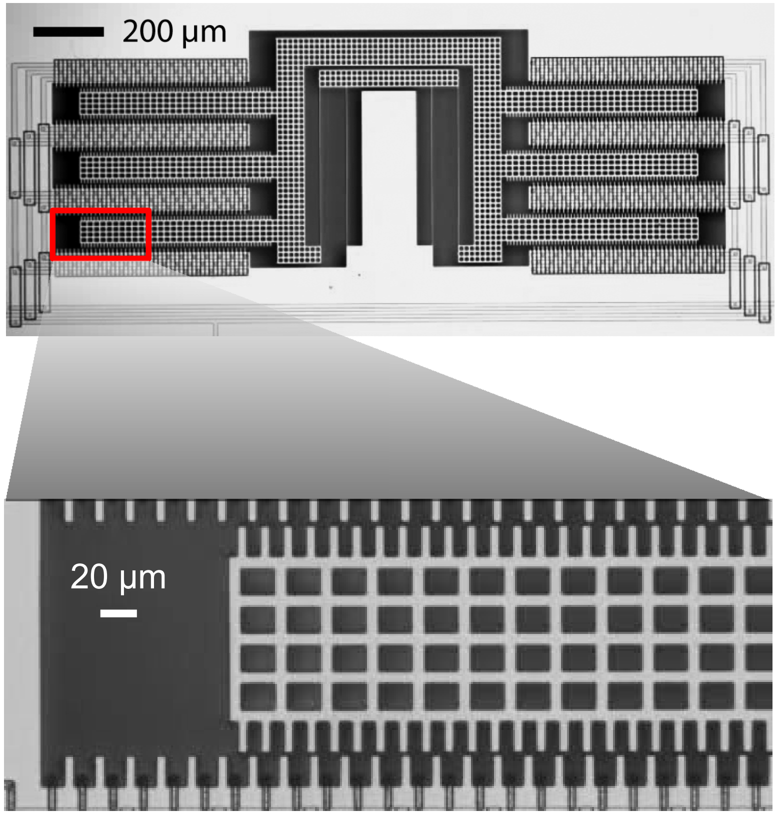
Need for precise in-plane MEMS characterization

- Process dependent properties
- Device calibration

Existing solutions

- Solid-state integrated sensor
- Optical methods (*e.g.* stroboscopy, blurred imaging, high speed camera)

We propose a straightforward optical method based on DFT image analysis.

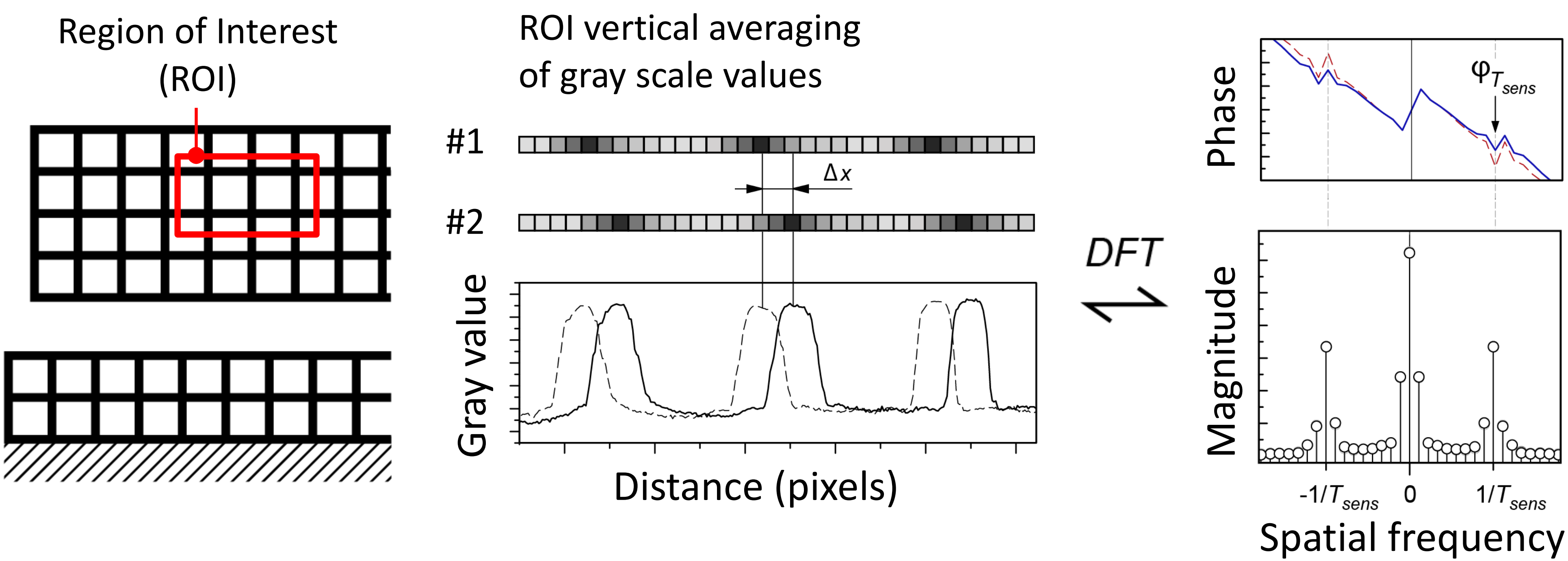


E. Sarajlic *et al.*, "Electrostatic 3-phase linear stepper motor fabricated by vertical trench isolation technology," *J. Micromech. Microeng.* ***19*** (7), No. 074001, 2009

Working principle | Discrete Fourier Transform

Discrete Fourier Transform (DFT) analysis of moving periodic patterns

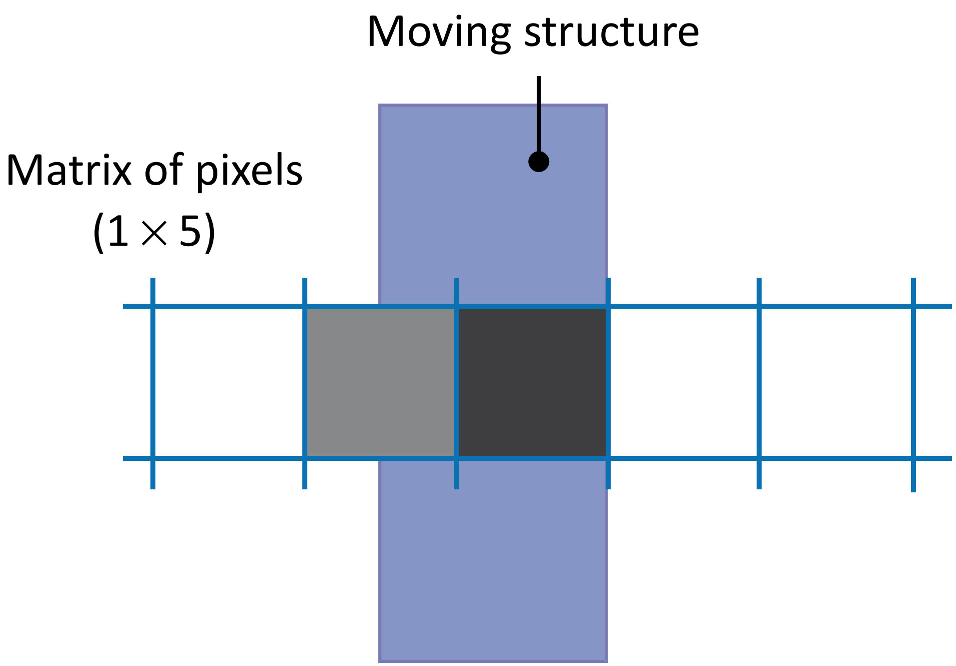
Algorithm based on the phase-shift method.

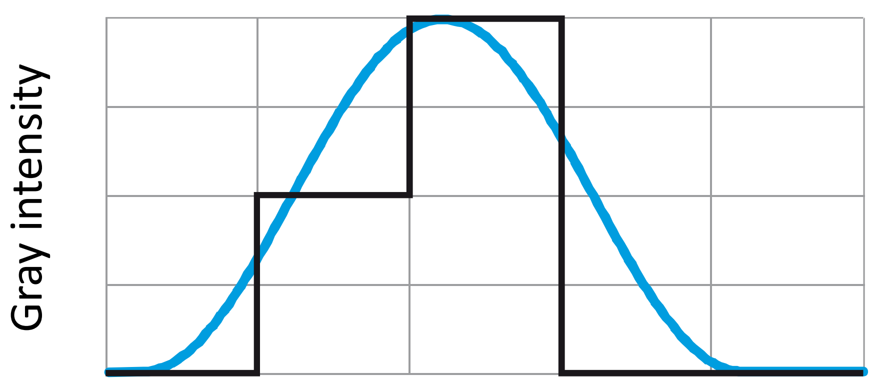


Video frames (2D) → *Spatial domain (1D)* → *Frequency domain*

C. Yamahata, E. Sarajlic, G.J.M. Krijnen, and M.A.M Gijs,
"Subnanometer Translation of Microelectromechanical Systems Measured by Discrete Fourier Analysis of CCD Images,"
J. Microelectromech. Syst. **19** (5), pp. 1273-1275, 2010.

Working principle | How subpixel resolution is possible?





Subpixel resolution can simply be obtained by gray scale level interpolation.

Enhancement:

- Periodic patterns
- Large matrix of pixels

For further mathematical details, see reference below.

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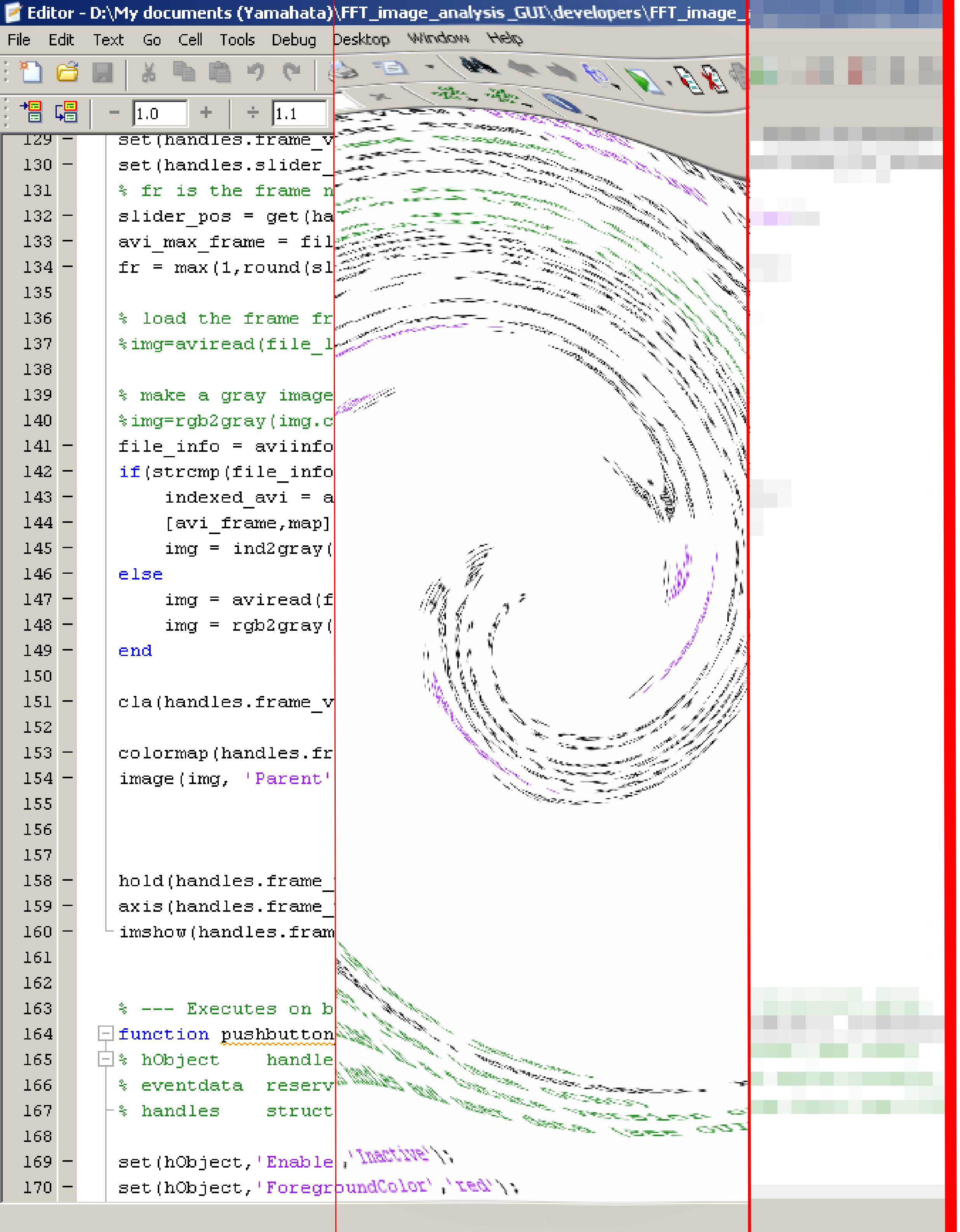


Computing software

→ MATLAB Graphical User Interface (GUI)

Computing software | MATLAB GUI

Step 1: Video selection

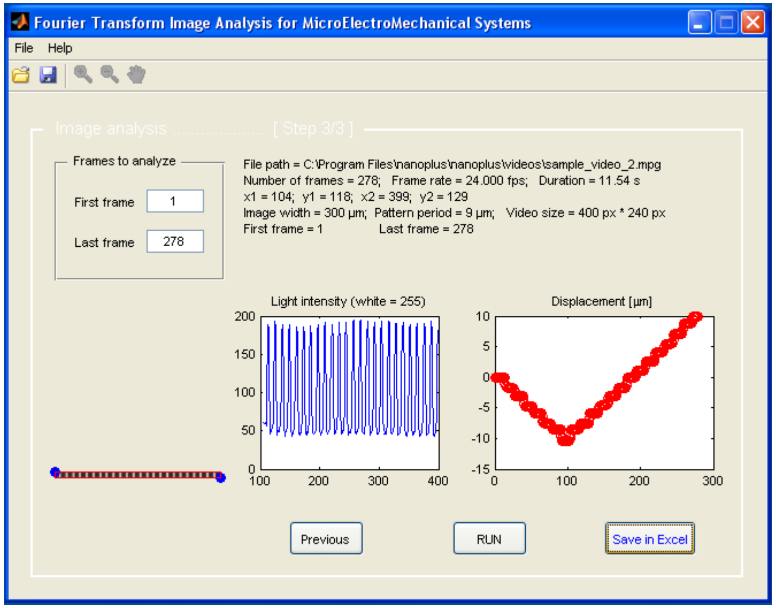
- **AVI** file (compressed or uncompressed)
- Any MATLAB compatible codec (*e.g.* mpeg, wmv)

Step 2: Area selection

- Select the **region of interest (ROI)**
- Set the parameters:
  - **scale** (video width)
  - **spatial period** of the structure

Step 3: Frame by frame analysis

➔ Data can be **saved in Excel**

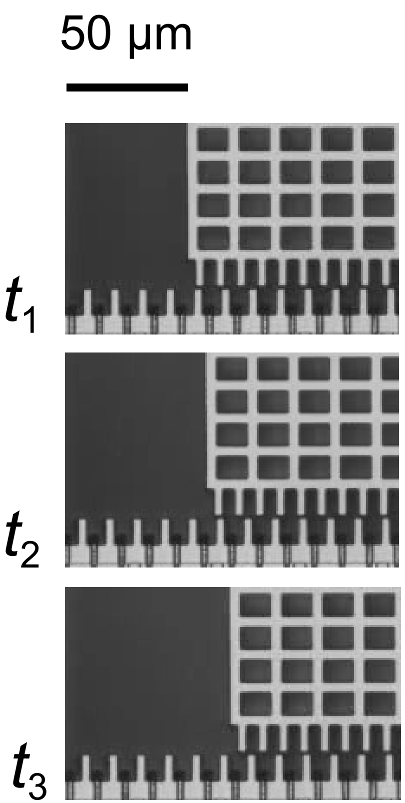


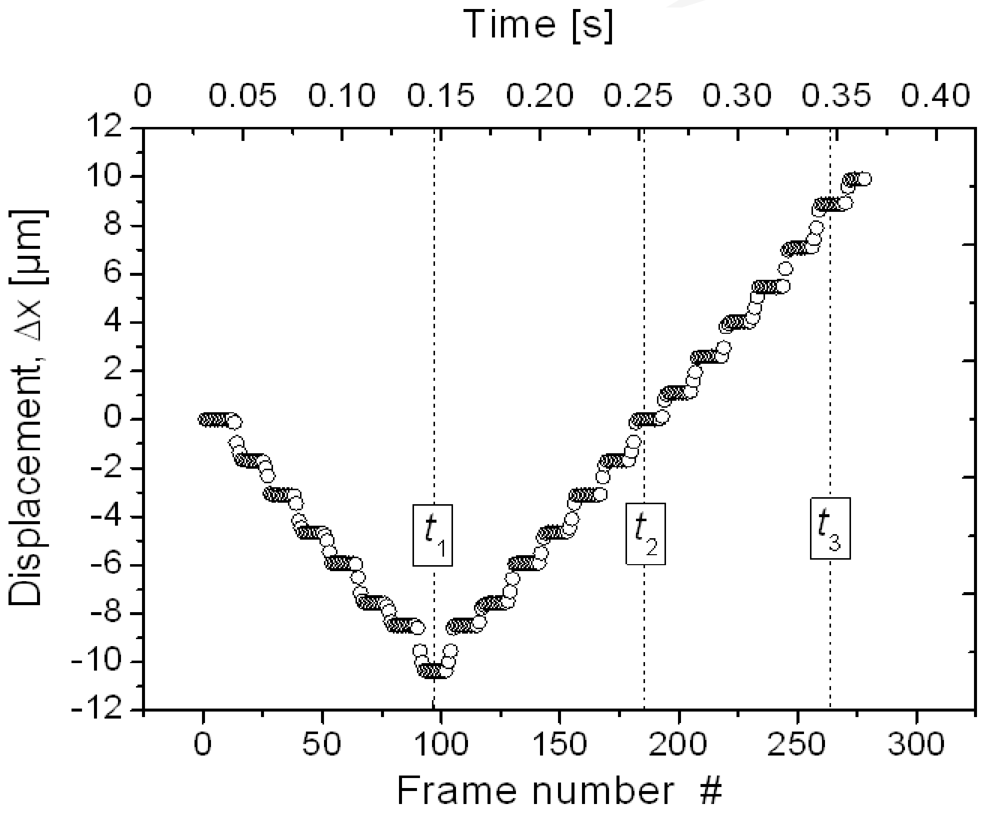
Demonstration video

Software freely available at http://lmis2.epfl.ch/nanoplus/

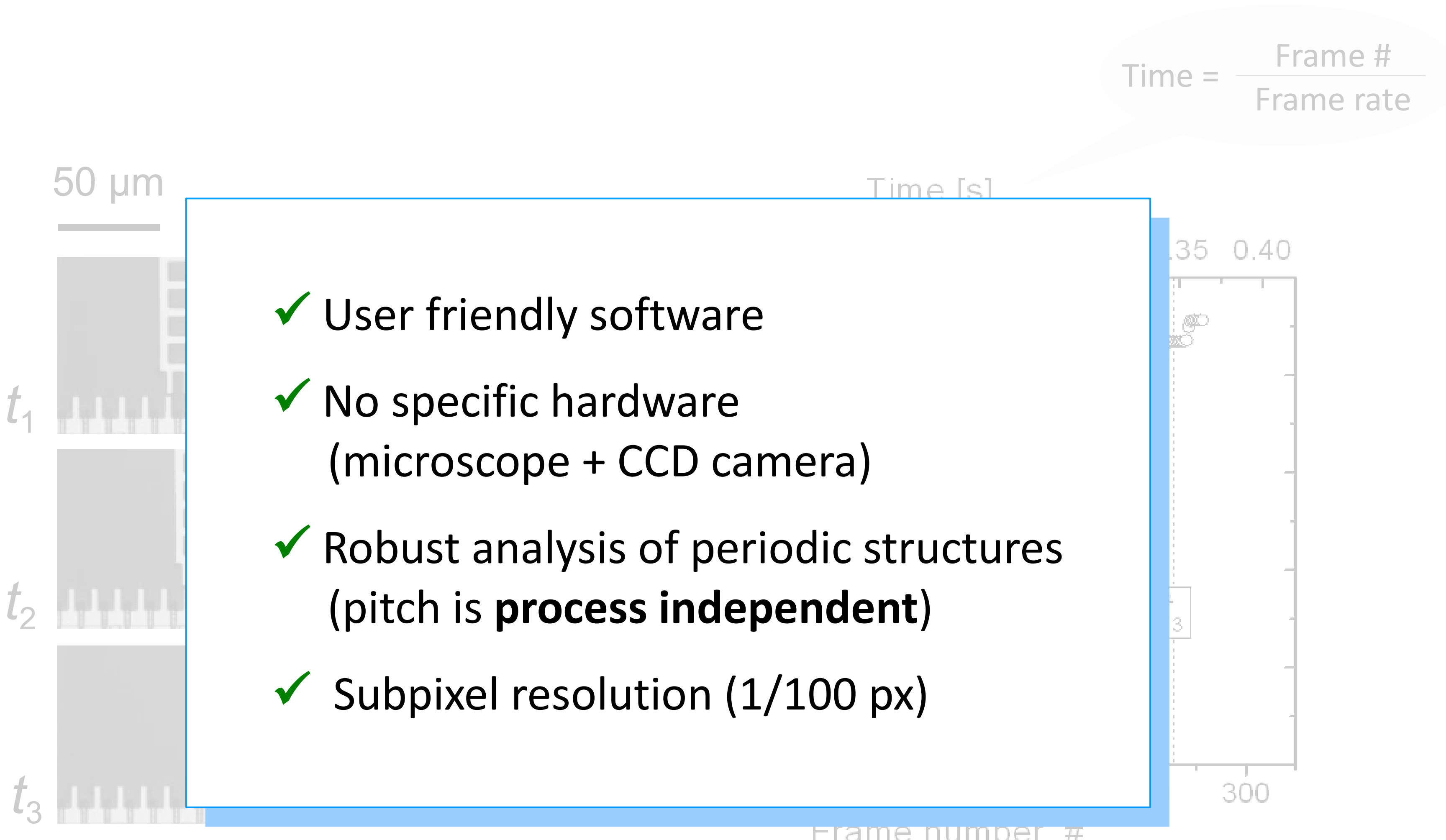
Computing software | MATLAB GUI

$$\text{Time} = \frac{\text{Frame \#}}{\text{Frame rate}}$$

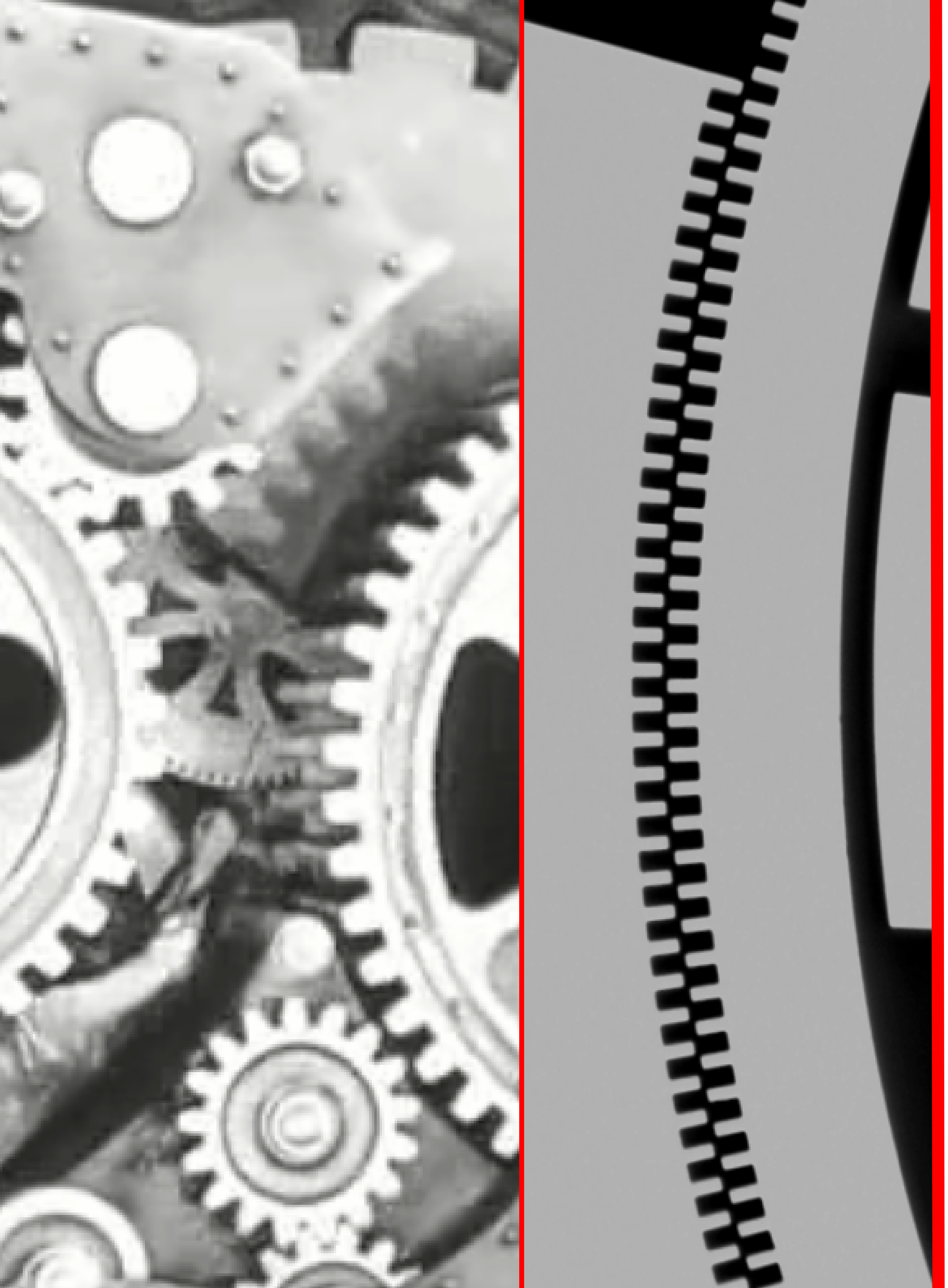




Computing software | MATLAB GUI



- ✓ User friendly software
- ✓ No specific hardware
  (microscope + CCD camera)
- ✓ Robust analysis of periodic structures
  (pitch is **process independent**)
- ✓ Subpixel resolution (1/100 px)

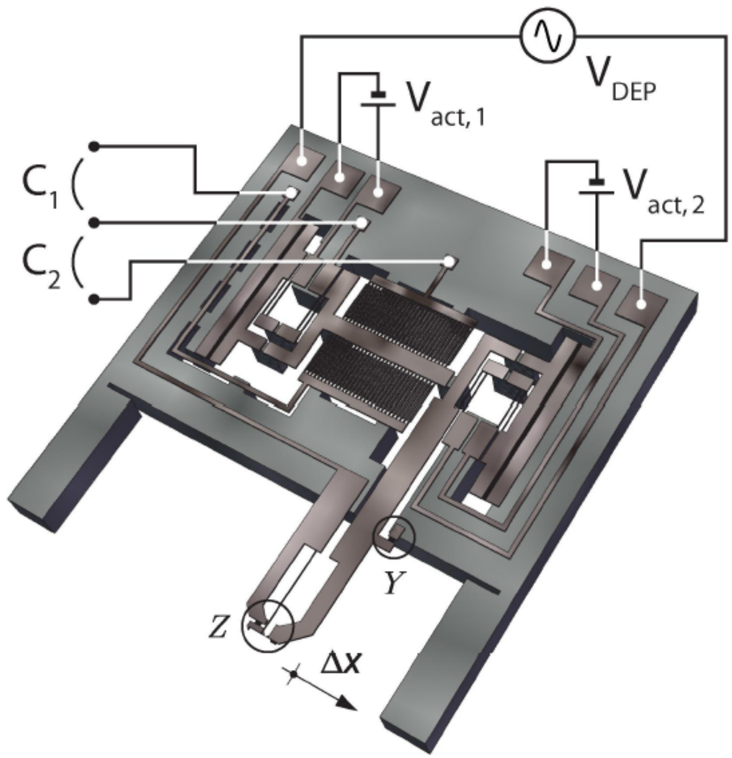


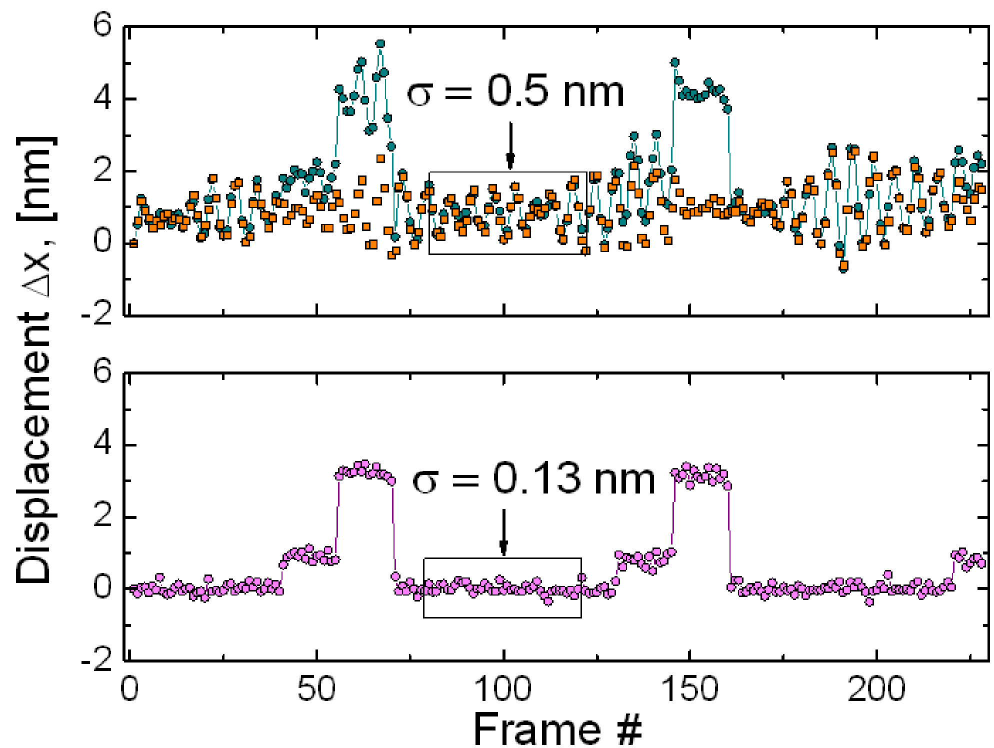
Static measurements

- Subpixel resolution
- Effect of vibrations

Static Measurements | Application to MEMS

Case 1: Subpixel resolution by relative displacement analysis





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"Mechanical Characterization of Biomolecules in Liquid Using Silicon Tweezers with Subnanonewton Resolution,"
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Static Measurements | Application to MEMS

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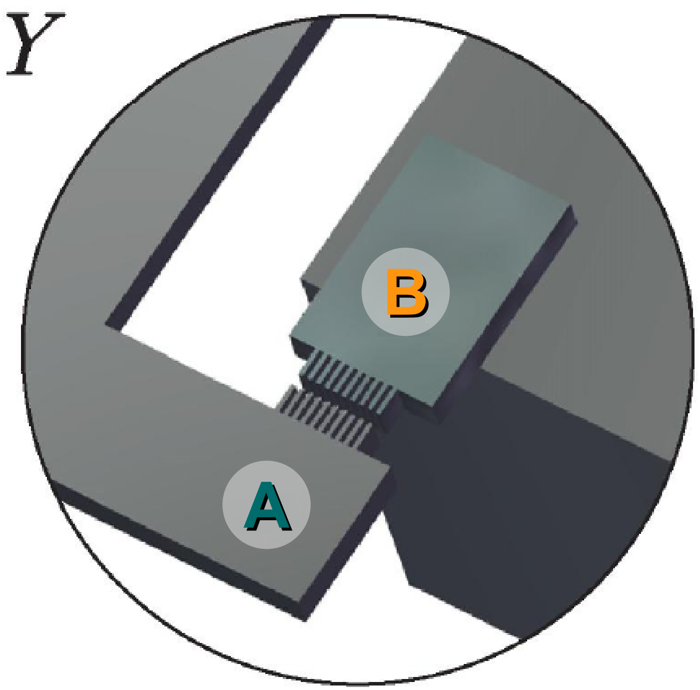

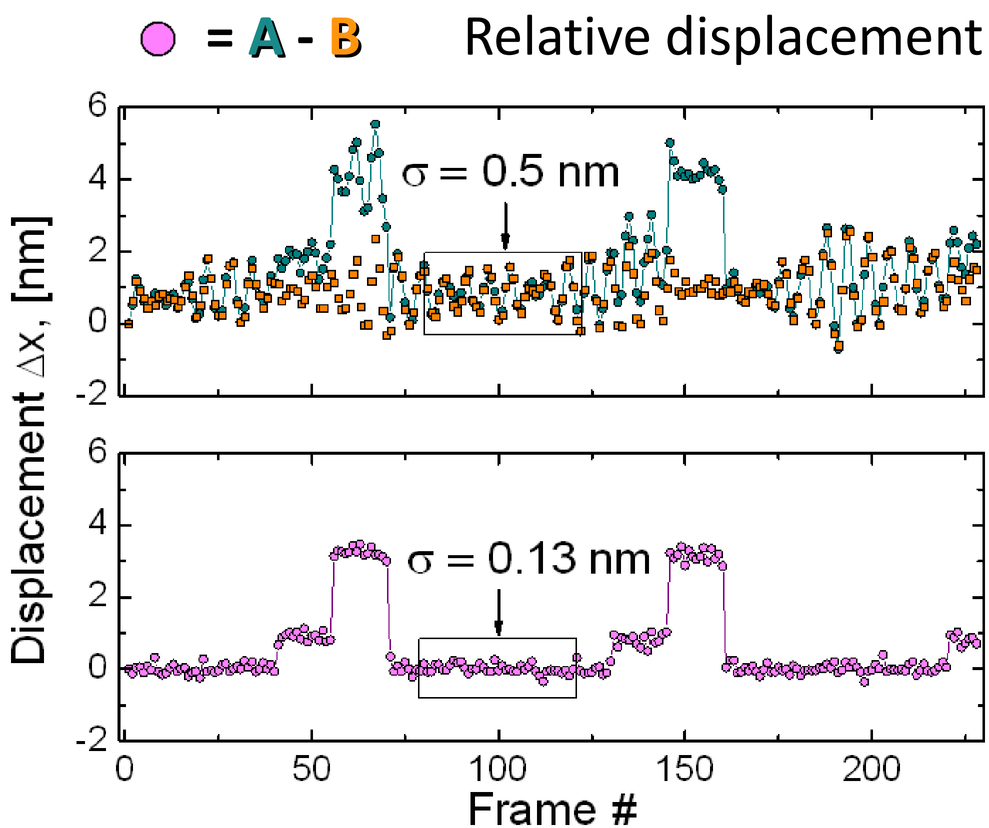

A Moving structure

B Reference patterns

Pixel 75 × 75 nm ⇨ 1/100 px resolution

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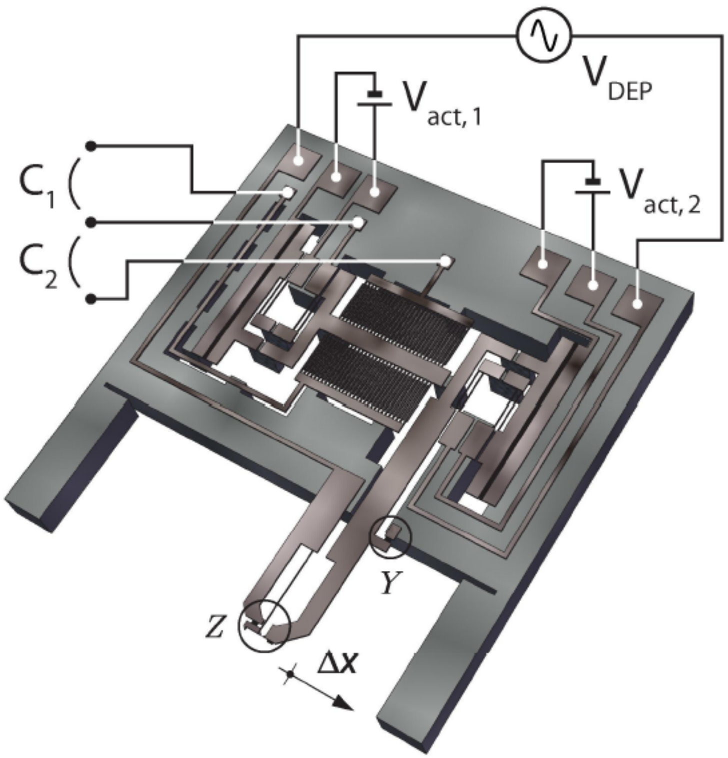
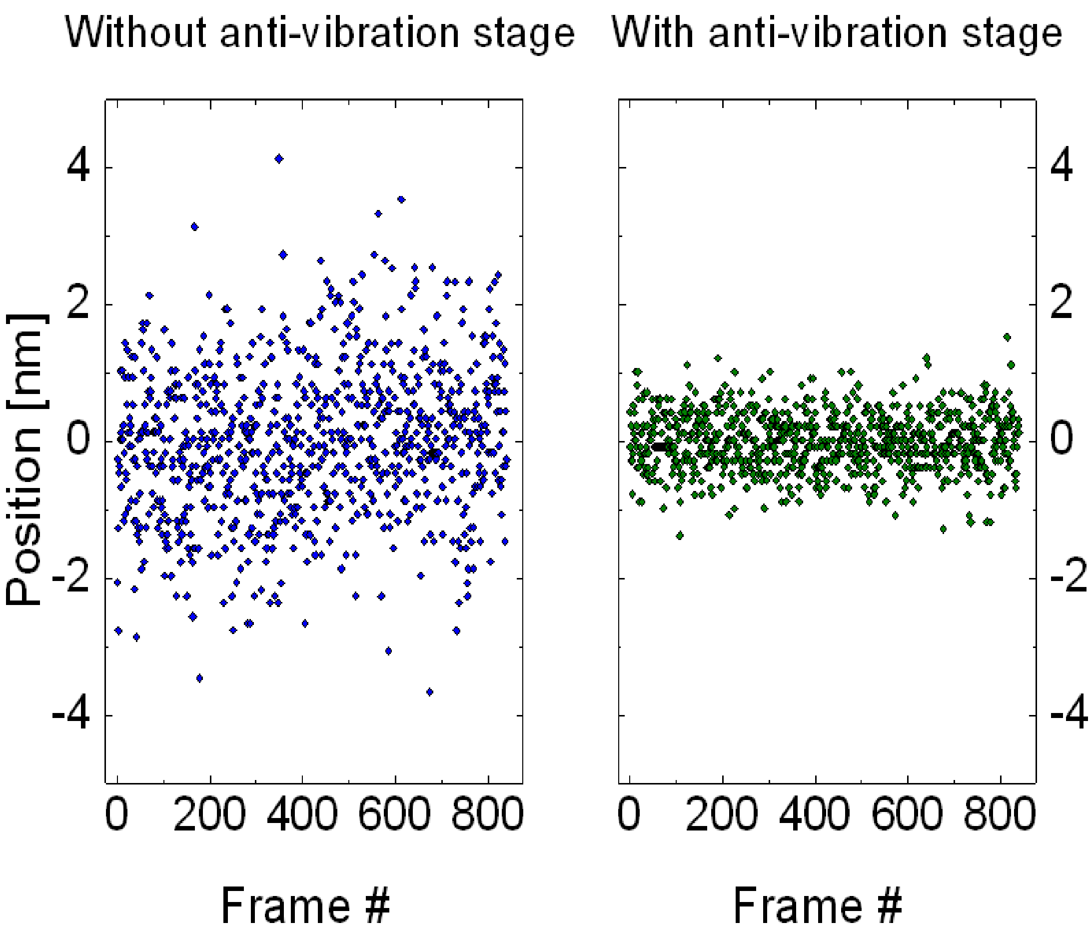
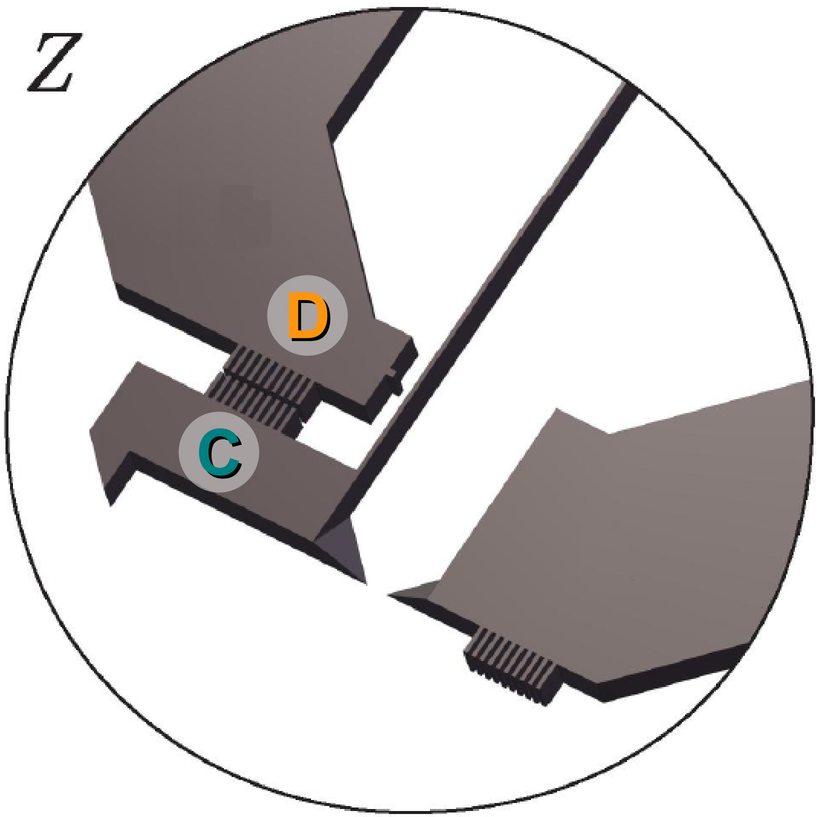
Case 2: Effect of vibrations





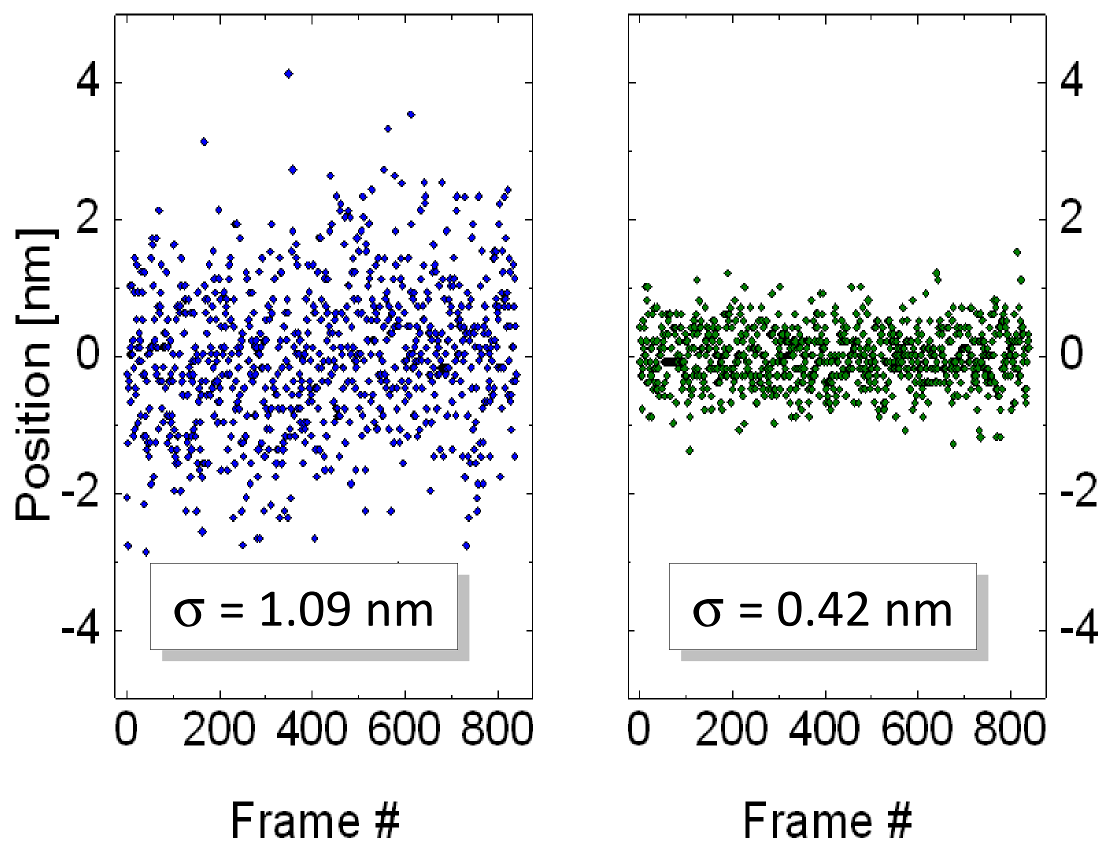
Static Measurements | Application to MEMS

Case 2: Effect of vibrations



C Moving structure
D Reference patterns

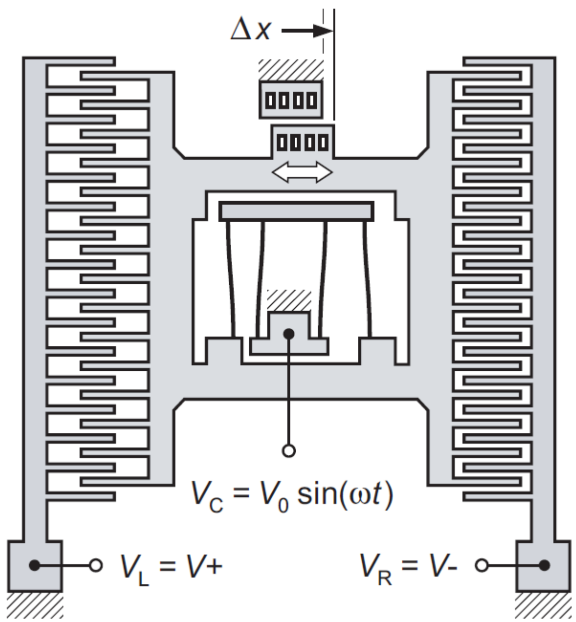
●/● = C - D Relative displacement

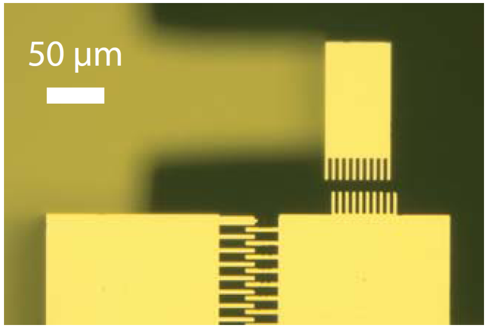


Dynamic measurements

- Aliasing effect
- Temporally aliased video microscopy

Case 3: Aliasing effect





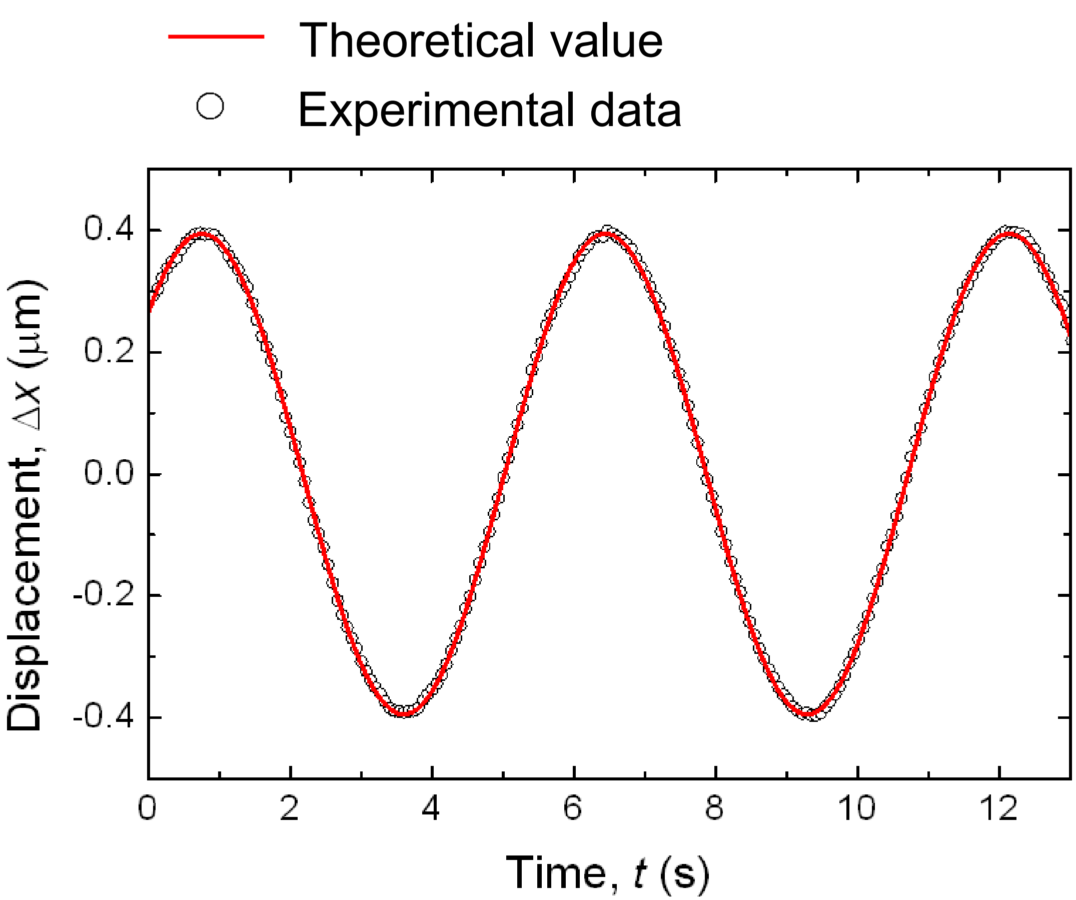
Video frame rate:
f_S = 14.9763 Hz
[$f_S \approx$ 15 fps (tech. spec.)]

Oscillation frequency:
$f_M = \omega/2\pi$ = 2007 Hz

Aliased frequency:
$f_{alias} = | f_M - N \times f_S |$ = 0.1758 Hz
with N = 134

➡ Shutter set to 1/5000 s

Case 3: Aliasing effect



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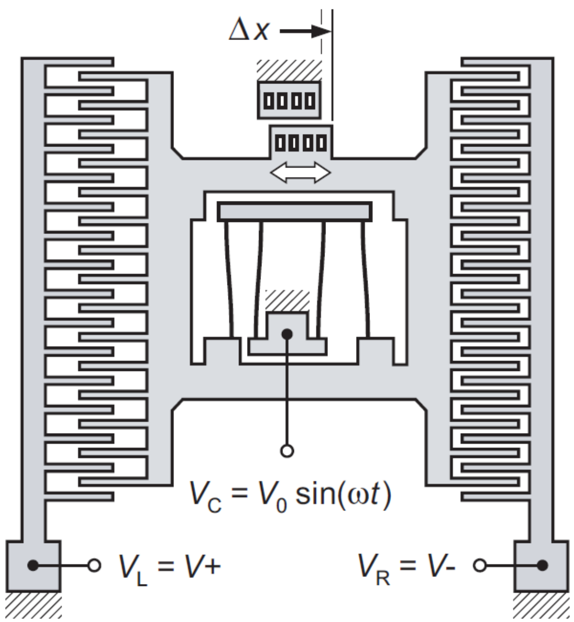
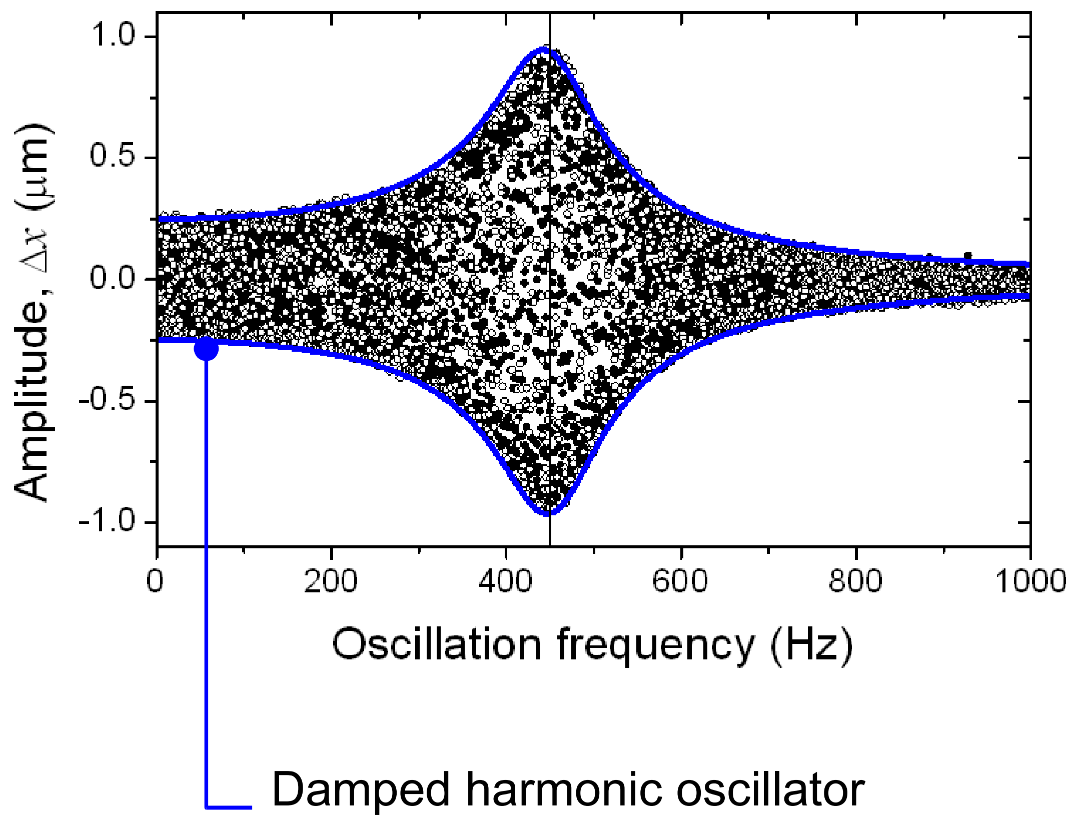
Case 4: Temporally aliased video microscopy





Video frame rates:
f_S = 15 fps (○) / 28 fps (●)

Frequency sweep:
f_M = 1 Hz – 1 kHz

Conclusion

Conclusion

Advantages of the proposed method:

- ✓ Subpixel resolution (1/100 px)
- ✓ In-situ measurement reference:
  Pattern period is process independent
- ✓ No specific hardware
  (microscope + CCD camera)
- ✓ User friendly software

Applications in the field of MEMS:

- Calibration
- Strain–stress measurements at the µm scale
- Experimental modal analysis

Software freely available at http://lmis2.epfl.ch/nanoplus/

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