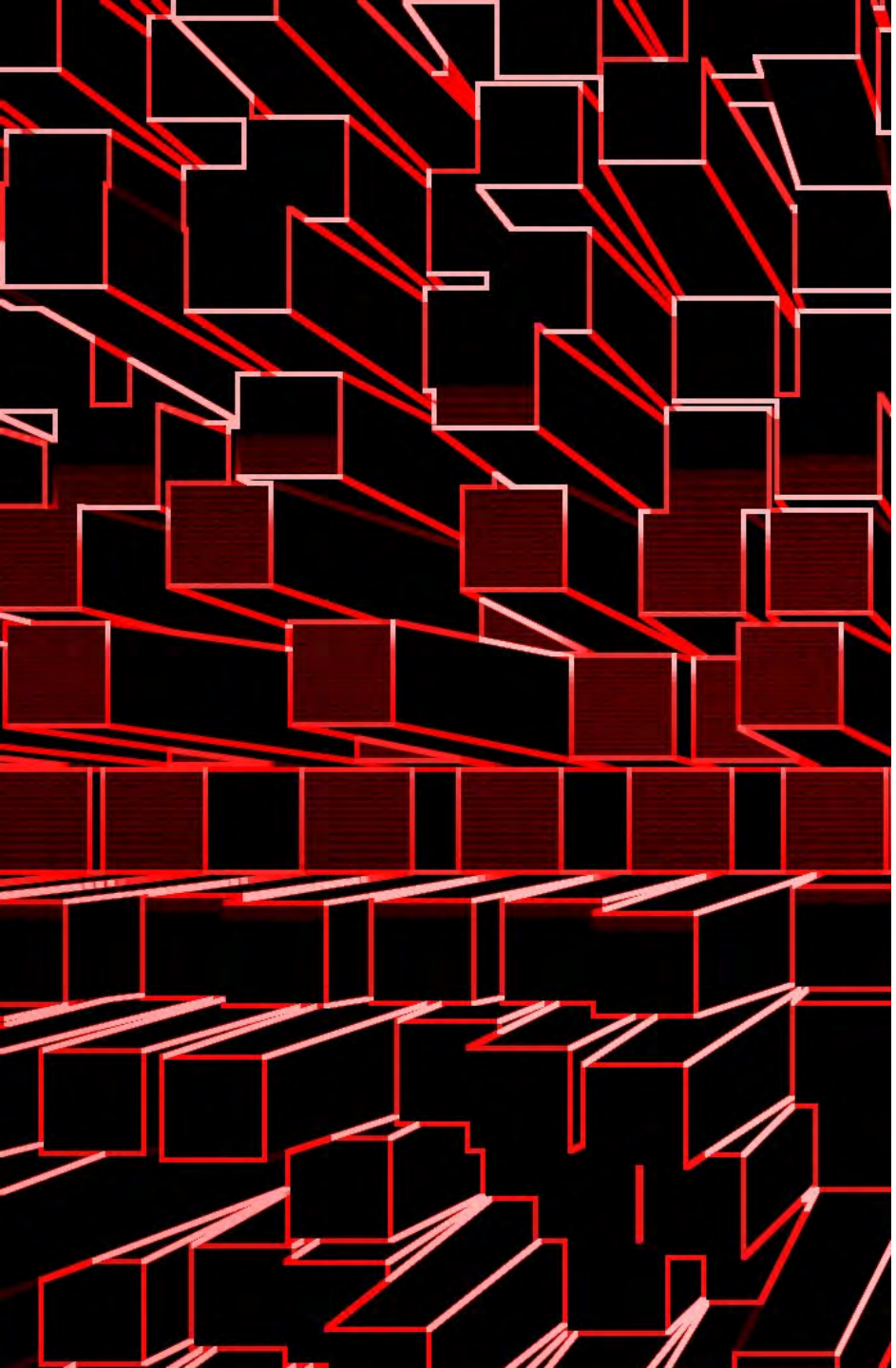


Subnanometer Displacements Measured by Fourier Transform Image Analysis

Christophe YAMAHATA,

Edin SARAJLIC,

Gijs J. M. KRIJNEN & Martin A. M. GIJS

EPFL, STI, IMT • Laboratory of Microsystems

May 2010

SmartTip Probe Solutions

University of Twente
Enschede - The Netherlands

EPFL
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Outline

Theoretical background

➔ Fourier transform applied to image analysis

Computing software

➔ MATLAB Graphical User Interface

Examples

- Movie scene with lots of gears
- Application to MicroElectroMechanical Systems (MEMS)

Conclusion & Outlook

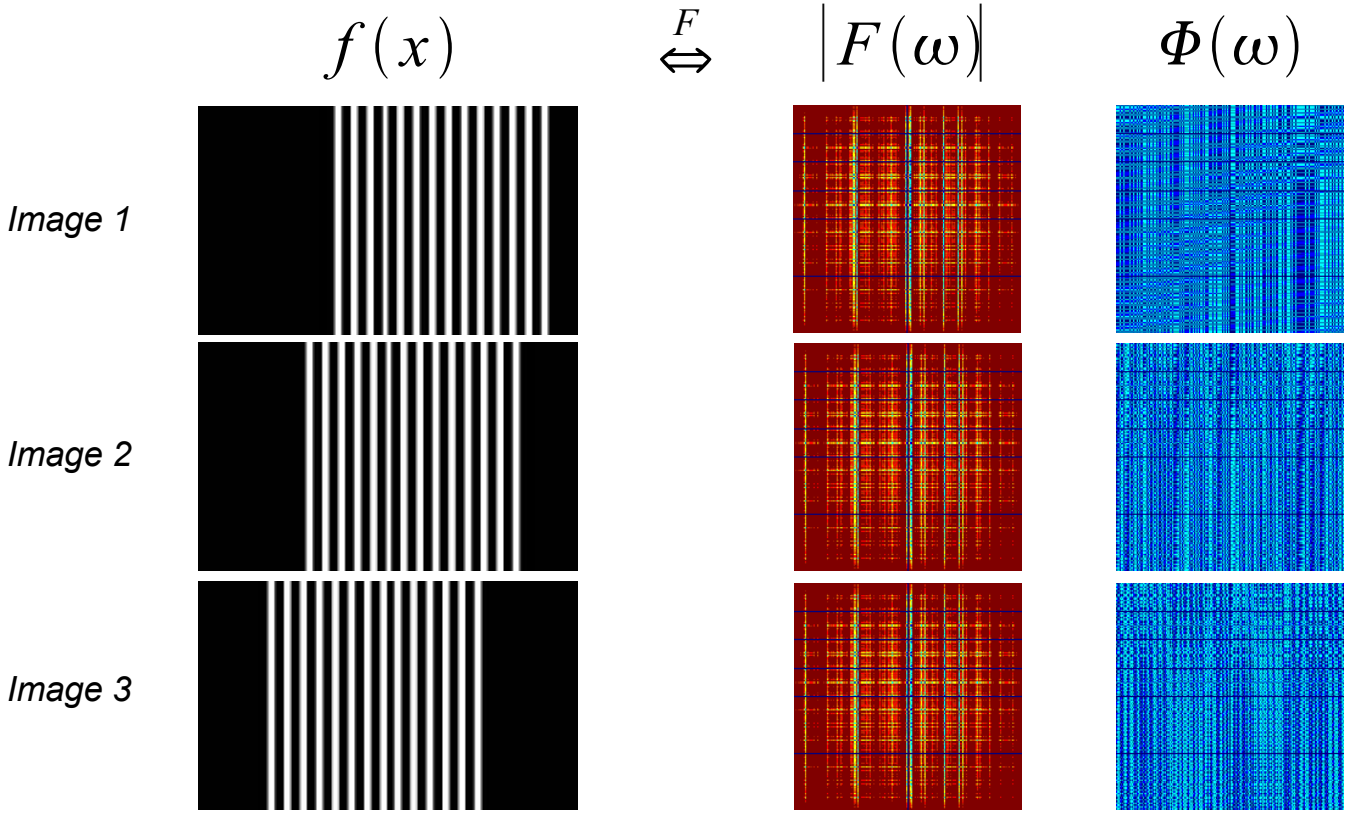
Theoretical background

- ➔ Fourier transform applied to image analysis

Displacement measurement by Fourier transform analysis

The Fourier transform can be applied to **images** (2D function).

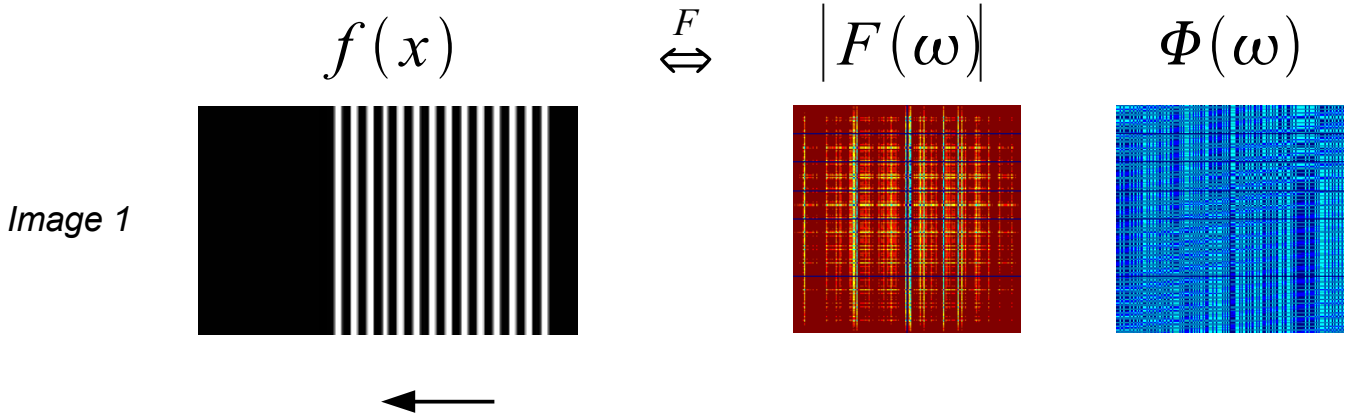
Example: Fast Fourier Transforms of images



Displacement measurement by Fourier transform analysis

The Fourier transform can be applied to **images** (2D function).

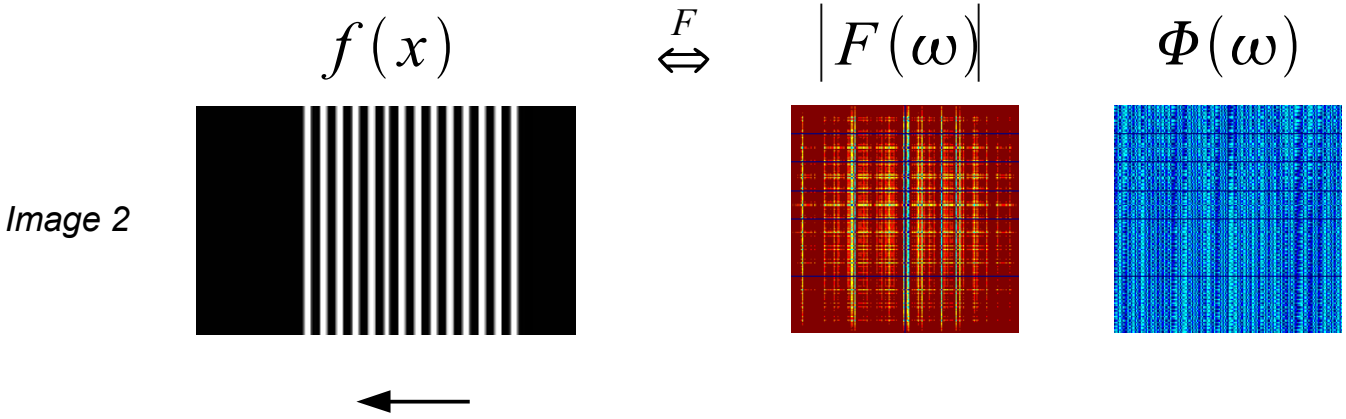
Example: Fast Fourier Transforms of images



Displacement measurement by Fourier transform analysis

The Fourier transform can be applied to **images** (2D function).

Example: Fast Fourier Transforms of images



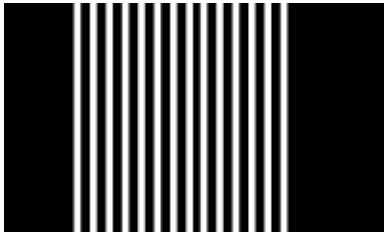
Displacement measurement by Fourier transform analysis

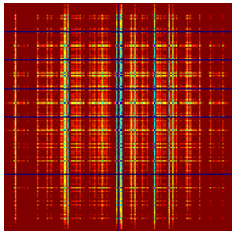
The Fourier transform can be applied to **images** (2D function).

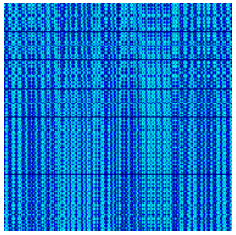
Example: Fast Fourier Transforms of images

$f(x) \overset{F}{\Leftrightarrow} |F(\omega)| \quad \Phi(\omega)$

Image 3





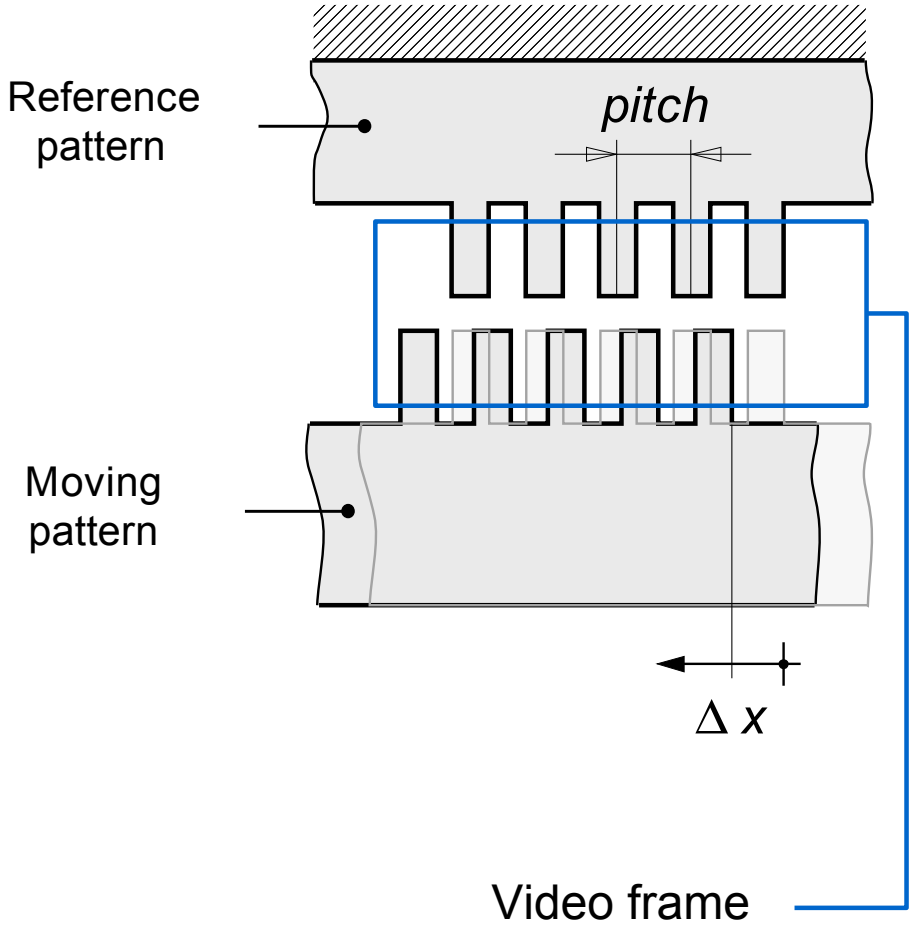


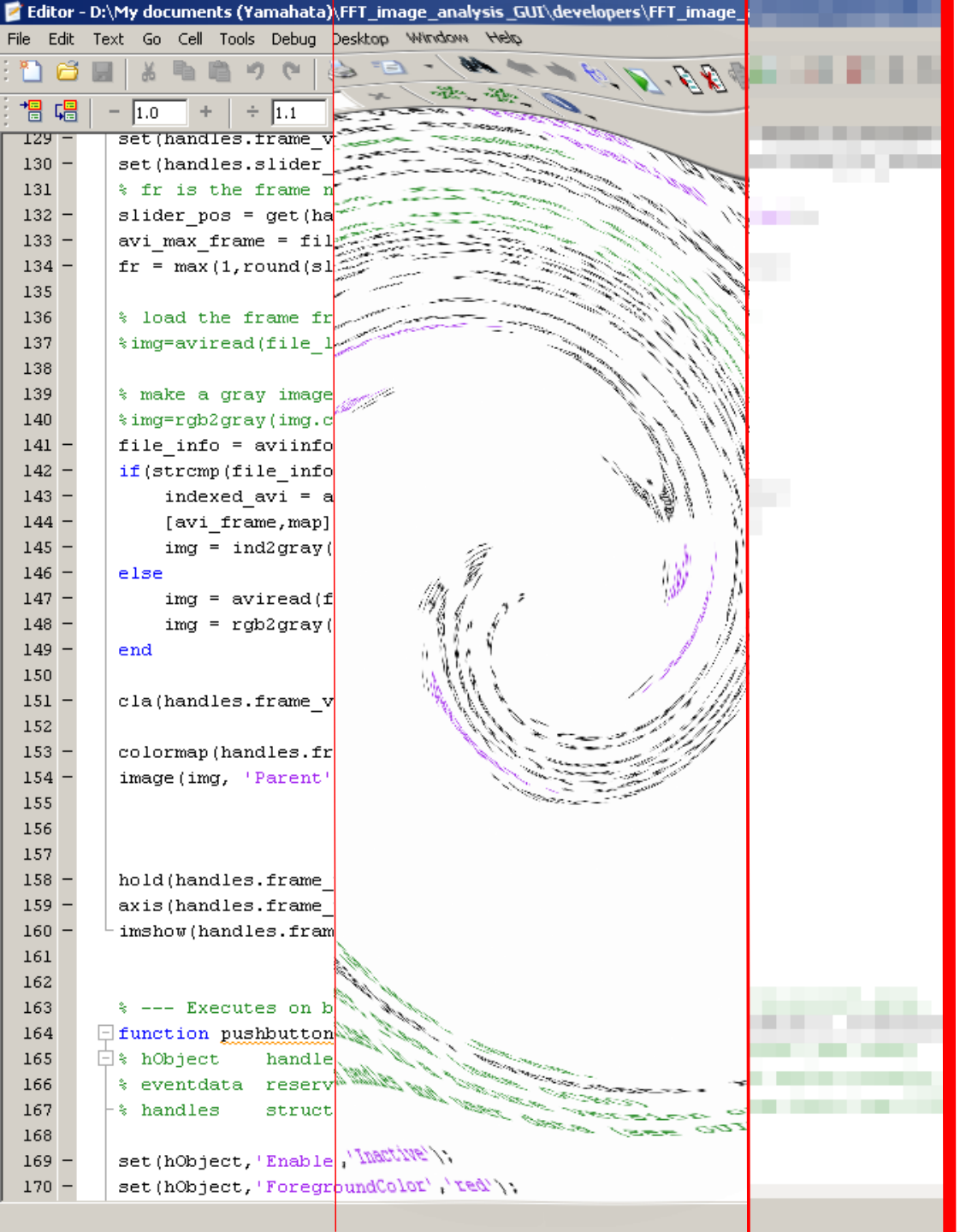
Pattern shift:
displacement to the left

Only the phase
changes

Measurement method | Fourier transform image analysis

Displacement measurement by Fourier transform analysis

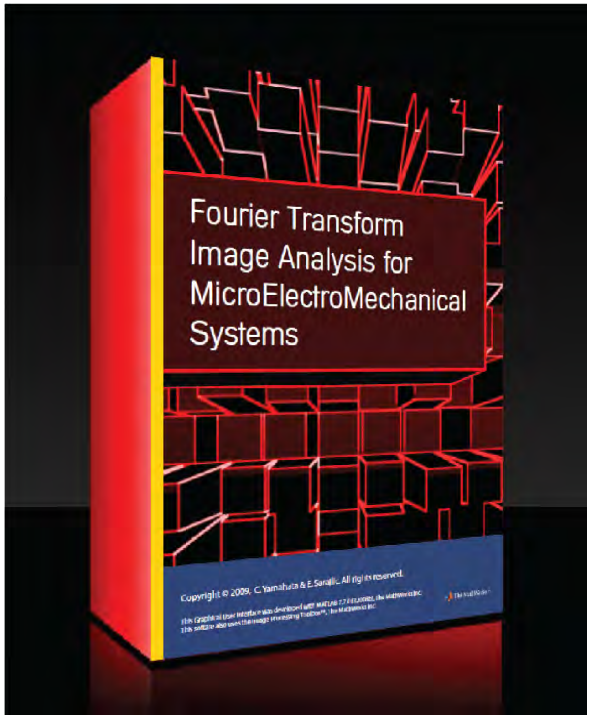




Computing software

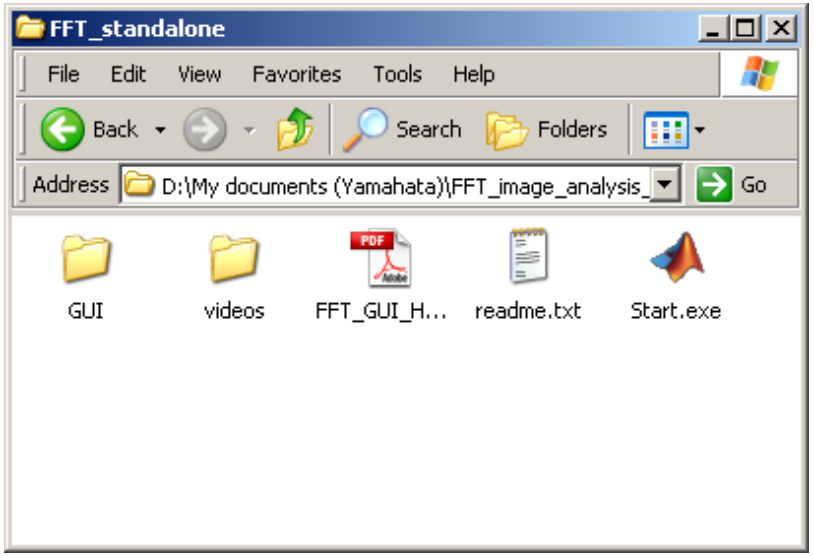
- MATLAB Graphical User Interface (GUI)

Computing software | MATLAB GUI



nano+ | Metrology for MEMS

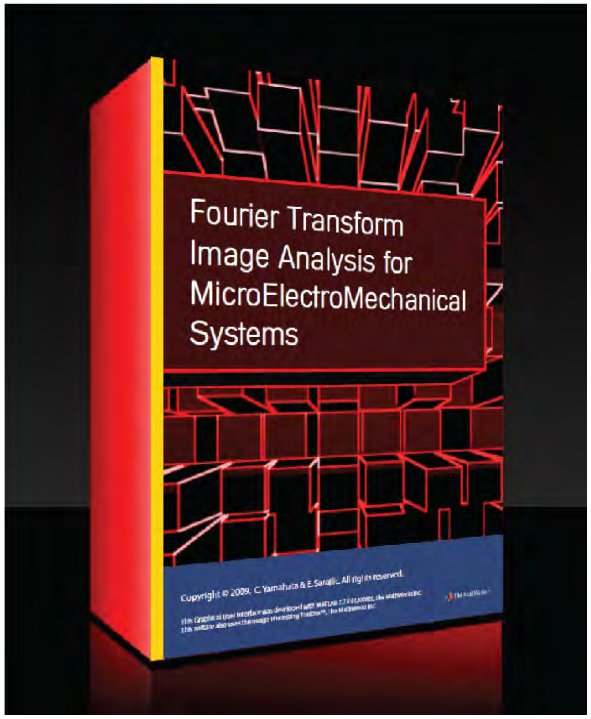
Available for download at
http://lmis2.epfl.ch/nanoplus/
(free of charge)



The self-extracting package contains:

- MATLAB source files
  (".m" script + ".fig" GUI)
- Standalone executable file (Windows)
- Sample videos
- Help document

Computing software | MATLAB GUI



nano+ | Metrology for MEMS

Available for download at
http://lmis2.epfl.ch/nanoplus/
(free of charge)

Step 1: AVI selection

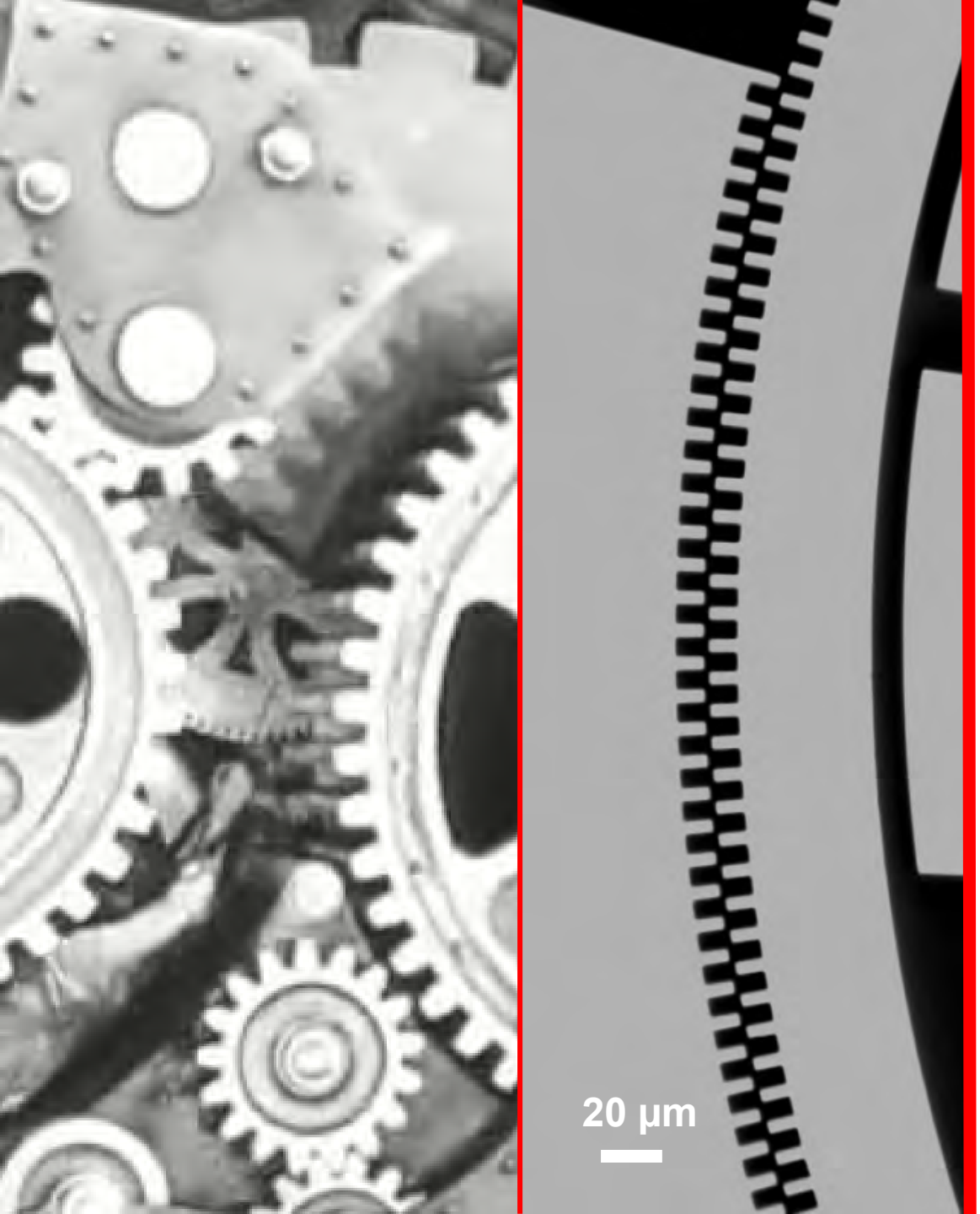
- Uncompressed **AVI file** (recommended)
- AVI compressed with a MATLAB compatible compression codec:
  - Cinepak
  - Indeo3, Indeo5
  - MSVC (Microsoft Video 1)
  - 8-bit RLE, etc.

Step 2: Area selection

- Select the **area of interest**
- Provide the **period** of the repeating patterns and the **width** of the video

Step 3: Image analysis

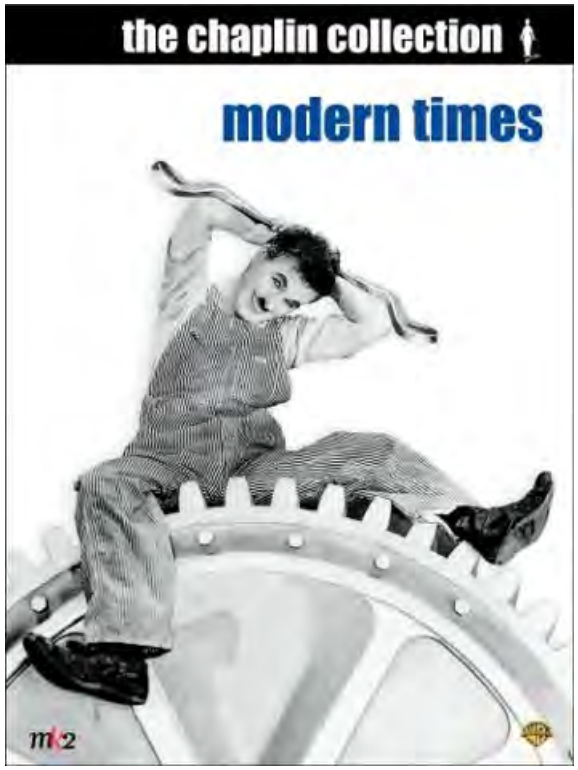
➔ Data can be **saved in Excel**



Examples

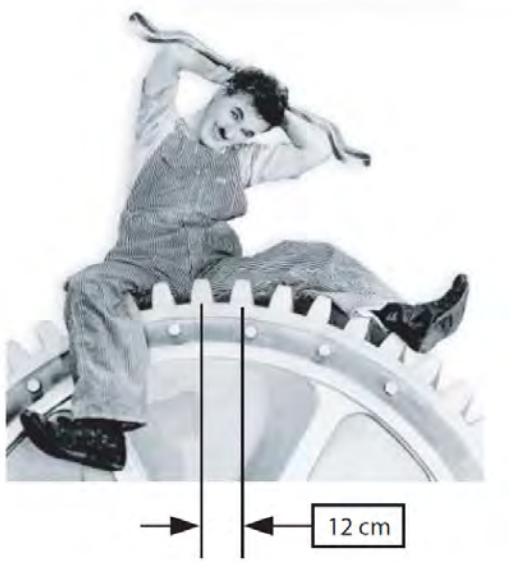
- Movie scene with lots of gears
- Application to MEMS

Examples | Movie scene with lots of gears



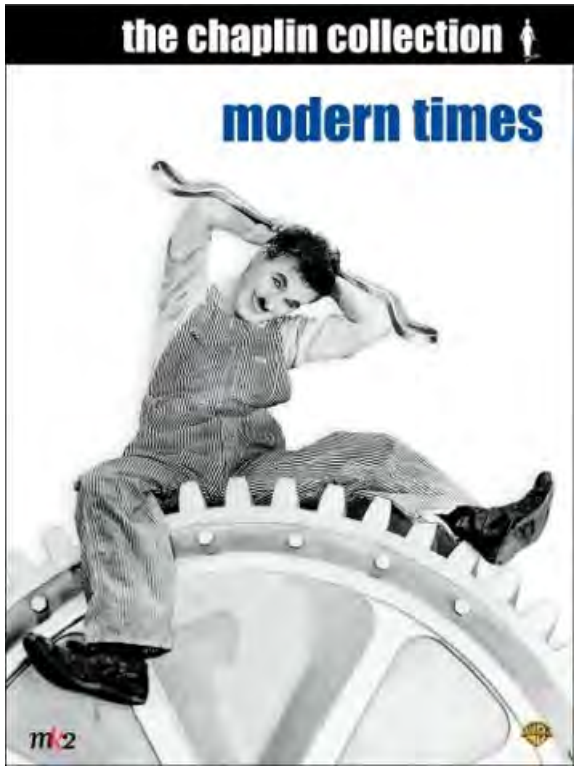
Trailer available online at
http://www.kino.com/moderntimes/

Parameters



➔ The **period** of the repeating patterns, as well as the **width** of the video can be estimated (roughly).

Examples | Movie scene with lots of gears



Trailer available online at
http://www.kino.com/moderntimes/

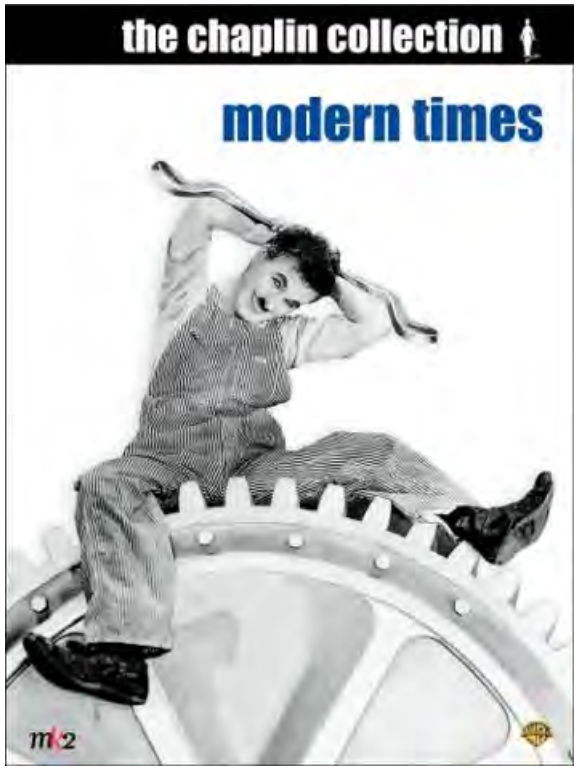
Results

➔ Even though the camera is moving during the sequence, we can use the big gearing to estimate the displacement.

Discussion

- **Camera position** must be:
  - Fixed
  - Perpendicular to the scene
- **Frame rate** must be high to avoid undersampling
  - Avoid aliasing
  - Eliminate wagon-wheel effect (Nyquist–Shannon sampling theorem)
- **Illumination** must be uniform (no shadowing)

Examples | Movie scene with lots of gears

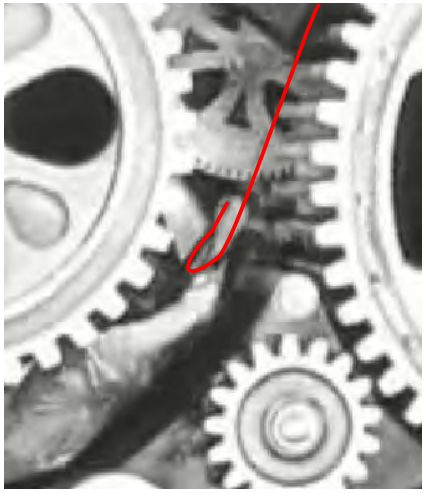


Trailer available online at
http://www.kino.com/moderntimes/

Results

➔ Even though the camera is moving during the sequence, we can use the big gearing to estimate the displacement.

Did you notice anything else?



Examples | Application to MEMS

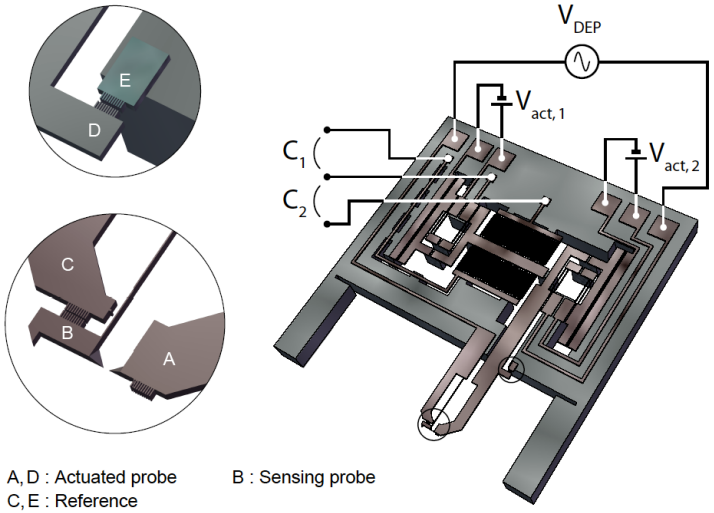
Example 1: Calibration of a capacitive sensor

Measurement method:

Spatial Fourier transform (imaging)
+ Differential Capacitive Sensor

FFT method:

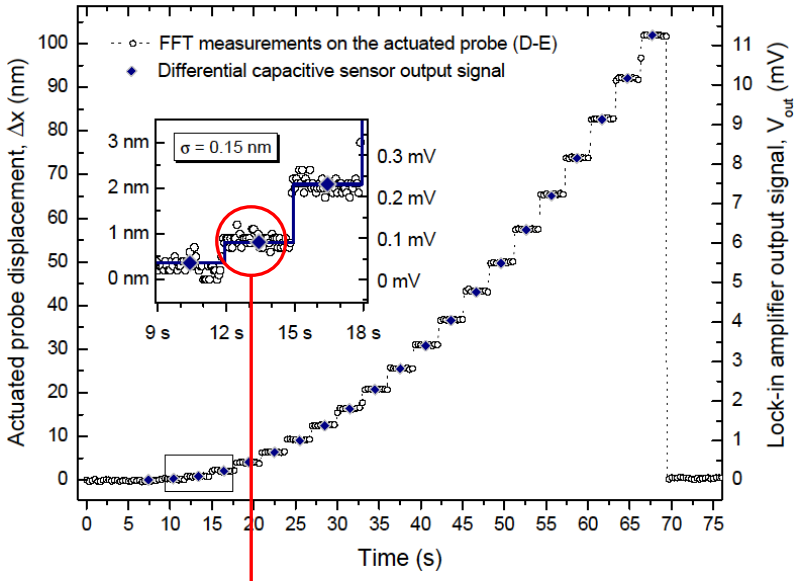
- Magnification × **5000**
- AVI video **800 × 600 pixels (15 fps)**



A, D : Actuated probe
C, E : Reference

B : Sensing probe

Electrostatic actuation of the moving probe ($V_{act,1}$ = 0; 0.5 V; 1 V; …; 10 V)



Standard deviation (FFT):

σ = 0.15 nm

C. Yamahata, E. Sarajlic, L. Jalabert, M. Kumemura, D. Collard and H. Fujita
"Mechanical Characterization of Biomolecules in Liquid Using Silicon Tweezers with Subnanonewton Resolution,"
Proc. 22nd IEEE Int. Conf. on Micro Electro Mechanical Systems (MEMS 2009), pp. 607-610, Sorrento, Italy, 2009.

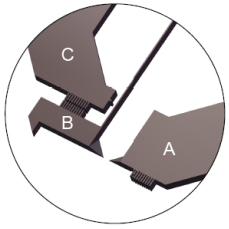
Examples | Application to MEMS

Example 2: Effect of vibrations

Measurement method:

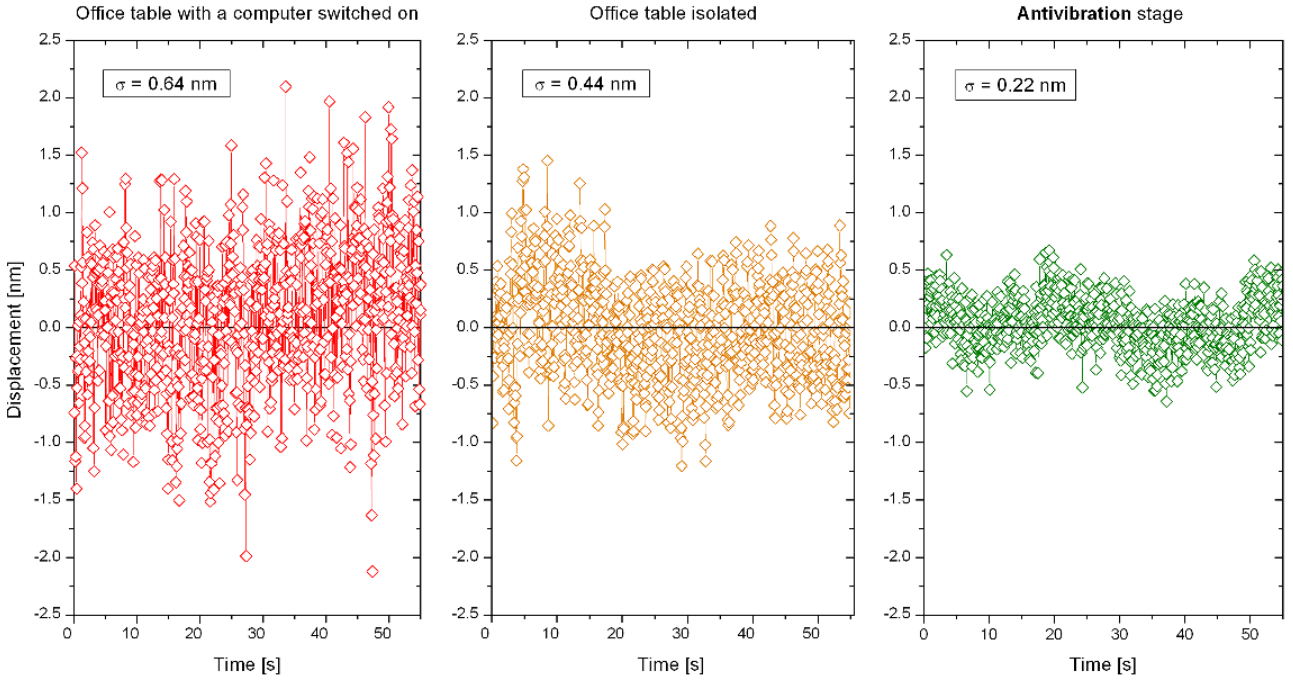
Spatial Fourier transform (imaging):

- Magnification × **5000**
- AVI video **800** × **600 pixels (15 fps)**



A, D : Actuated probe
C, E : Reference

B : Sensing probe



Examples | Application to MEMS

Example 3: Displacement of a comb-drive actuator

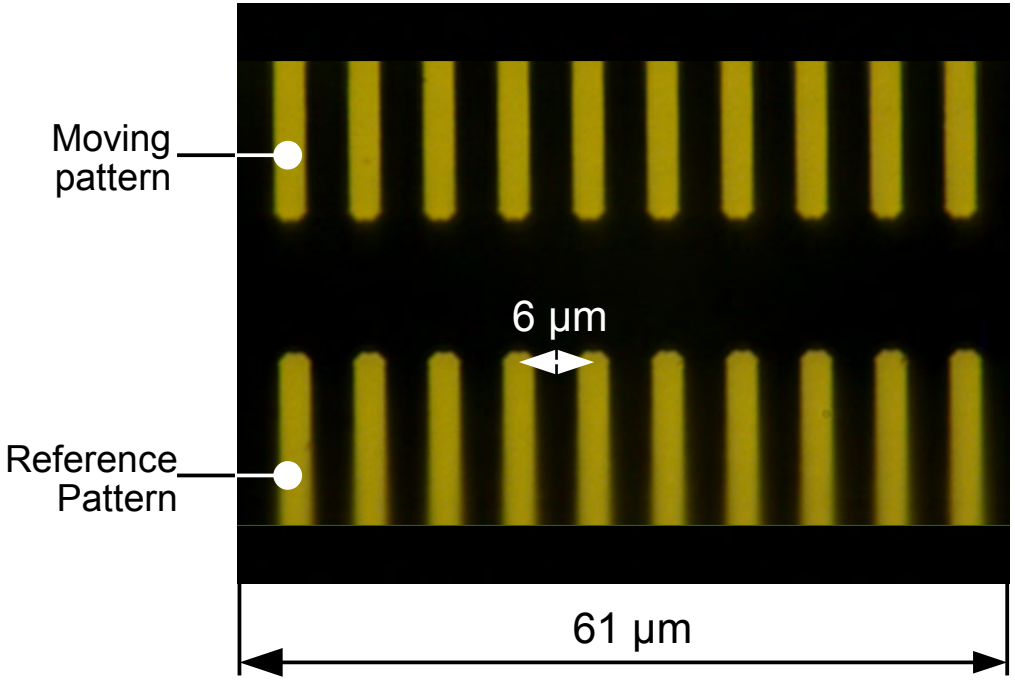
Measurement method:

Spatial Fourier transform (imaging):

- Magnification × **5000**
- AVI video **800** × **600 pixels (15 fps)**

Parameters:

- AVI width: **61 µm**
- Pattern period: **6 µm**



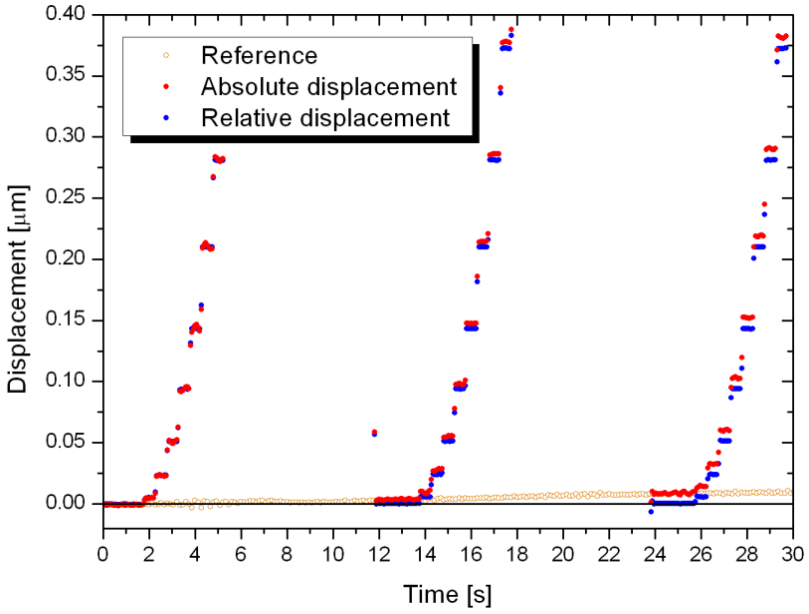
Examples | Application to MEMS

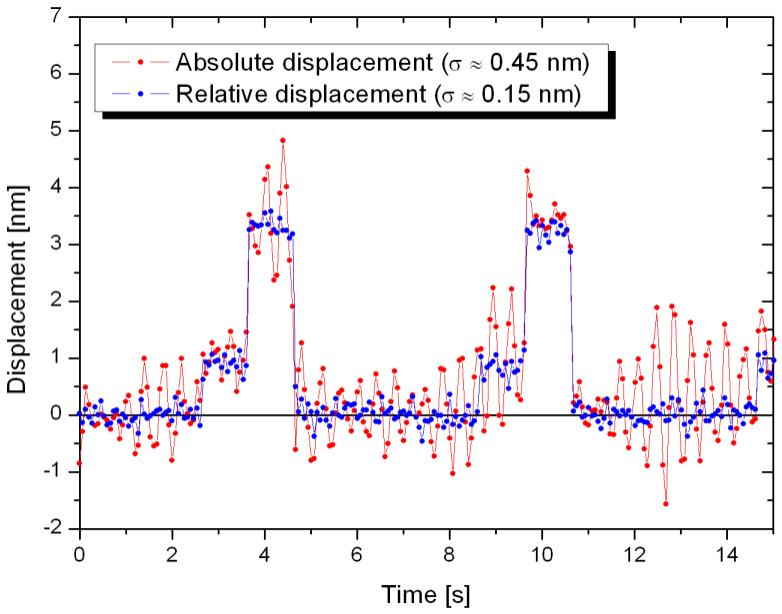
Example 3: Displacement of a comb-drive actuator

Measurement method:

Spatial Fourier transform (imaging):

- Magnification × **5000**
- AVI video **800 × 600 pixels (15 fps)**





Conclusion & outlook

Conclusion & Outlook

This method has been successfully used for the characterization of many types of MEMS devices.

- C. Yamahata *et al.*, “Mechanical characterization of biomolecules in liquid using silicon tweezers with subnanonewton resolution,” *Proc. IEEE MEMS*, pp. 607-610, Sorrento, Italy, January 25 – 29, 2009.
- E. Sarajlic *et al.*, “HAREM: High aspect ratio etching and metallization for microsystems fabrication,” *J. Micromech. Microeng.* **18** (7), 075008 (2008).
- E. Sarajlic *et al.*, “An electrostatic 3-phase linear stepper motor fabricated by vertical trench isolation technology,” *J. Micromech. Microeng.* **19** (7), 074001 (2009).
- and several other unpublished results ...

Many applications in the field of MEMS

- Easy to implement in any laboratory (digital camera attached to an optical microscope)
- Can be used to calibrate MEMS, perform strain/stress measurements at the micrometer scale, etc.