Measuring large areas by white light interferometry at the nanopositioning and nanomeasuring machine (NPMM)

Authors:
Daniel Kapusi¹
Torsten Machleidt
Karl-Heinz Franke
Eberhard Manske
Rainer Jahn

¹daniel.kapusi@tu-ilmenau.de
Outline

- Motivation
- Measurement setup
- Principles of scanning white light interferometry
- Interferogram analysis methods
- Measuring large areas
- Determination of sensors orientation and scaling
- Correction of sensors tilt
- Exemplary results
- Software environment
- Conclusion
- Outlook
NPMM features a measuring volume of 25 x 25 x 5 mm³ with a resolution of 0.1 nm

Advantages for white light interferometry

- Low positioning noise
- Large perpendicular pass trough range with 5 mm
- Stitching of adjacent single measuring results to a common large height map
Measurement setup

- White light interferometry sensor
  - Tube from a focus sensor coupled with a Mireau-interference objective
  - 14-bit monochromatic CCD camera (FireWire 1394b, up to 30 fps)
  - Halogen light source
- NPMM is placed on an oscillation-damping system
- Acoustic hood
Principles of scanning white light interferometry

- Camera
- 1388x1038 pixel
- White Light Interferometer
- Real camera image
- Stage (NPM-Machine)
- Object
- 1.44 Mio. pixel

Step size 77 nm
Scan direction
Principles of scanning white light interferometry

- **Stage (NPM-Machine)**
  - **Object**
  - **Camera**
    - 1388x1038 pixel
  - **White Light Interferometer**
  - **Step size 77 nm**
  - **Scan direction**
  - **Real camera image**
  - **1.44 Mio. pixel**

Speaker: Daniel Kapusi
52. International Scientific Colloquium
Principles of scanning white light interferometry

- Camera
  - 1388x1038 pixel
- White Light Interferometer
- Object
- Stage (NPM-Machine)

Real camera image

Scan direction

Step size 77 nm

1.44 Mio. pixel
Principles of scanning white light interferometry

- Camera: 1388x1038 pixel
- White Light Interferometer
- Object
- Stage (NPM-Machine)
- Real camera image
- Scan direction
- Step size 77 nm
- 1.44 Mio. pixel
Principles of scanning white light interferometry

Stage (NPM-Machine)

- Camera
  - 1388x1038 pixel
- White Light Interferometer
- Object

Scan direction

Real camera image

1.44 Mio. pixel
Principles of scanning white light interferometry

Step size 77 nm

Stage (NPM-Machine)

Camera
1388x1038 pixel

White Light Interferometer

Object

Real camera image

1.44 Mio. pixel
Principles of scanning white light interferometry

- Z-scan with determination of zero optical path difference per pixel
- Parallel measurement of 1.44 million data points (pixel)

3d estimation of the ring structure
Interferogram analysis methods

- **Envelope evaluation**
  - Suitable for rough and smooth surfaces
  - Envelope extraction by Matched Filters, Hilbert-Transformation, fast Bucket methods, et al
  - Approximation of the envelopes peak position by Gaussian or parabola fit, iterative gradient-based peak search, et al

- **Phase evaluation**
  - Suitable for smooth surfaces
  - Phase shift determination by fast Bucket methods (such as Carré) or more precise Fourier analysis
  - Allocation of fringe order by envelope evaluation or spatial phase unwrapping
Interferogram analysis methods

Comparison of the results of measuring a PTB layer thickness standard:

- Sampling step width in perpendicular direction: $dz = 77 \text{ nm}$
- Given step height (ISO 5436-1) of section $R1$: $H_{R1} = 69.1 \text{ nm} \pm 1.2 \text{ nm}$

Envelope evaluation:

\[
H_{R1,N=30} = 69.11 \text{ nm} \pm 0.19 \text{ nm} \\
\sigma(H_{R1,N=30}) = 0.51 \text{ nm}
\]

Phase evaluation:

\[
H_{R1,N=30} = 69.26 \text{ nm} \pm 0.04 \text{ nm} \\
\sigma(H_{R1,N=30}) = 0.11 \text{ nm}
\]
Measuring large areas

- **Perpendicular orientation**
  - Skipping of height-steps with high speed, where no fringes occurring
  - Definition of multiple pass-through ranges per measuring area

- **Lateral orientation**
  - Topography independent stitching of adjacent measuring areas
  - Orientation and pixel scaling of the camera according to the machine coordinate system has to be determined

![Diagram showing measuring areas and range orientations](image)
Determination of sensors orientation and scaling

shortcuts:
- M - machine coordinate system
- S - sensor coordinate system
- Dist - distance vector
- T - affine transformation matrix

grid on calibration target (line spacing 50µm)

Hough-Transformation

Find corresponding point pairs (line intersections) by nearest neighbour criterion

$\mathbf{T}_{SM} \text{ (a priori)}$

Calc Transformation

$\begin{bmatrix} x_M \\ y_M \end{bmatrix}$

$\begin{bmatrix} x_M + dx_M \\ y_M + dy_M \end{bmatrix}$

$\begin{bmatrix} dx_M \\ dy_M \end{bmatrix}$

$\begin{bmatrix} dx_s \\ dy_s \end{bmatrix}$

$\begin{bmatrix} \frac{dx_s}{dy_s} \end{bmatrix}$

Calculation steps:

$\mathbf{Dist}_{M12} = \begin{bmatrix} dx_M \\ dy_M \end{bmatrix}$

$\mathbf{Dist}_{S12} = \begin{bmatrix} \frac{dx_s}{dy_s} \end{bmatrix}$
Correction of sensors tilt

tilted sensor array

first measuring area

second measuring area

height -offset

object surface

overlap

$z$

$x_s$ resp. $y_s$
Exemplary results

- Ring structures
  - Stitching of 3 x 2 regions (1.79 mm x 1.20 mm)
  - Two pass-through ranges at each single region

Speaker: Daniel Kapusi

52. International Scientific Colloquium
Software environment

- **Software package VIP (Visual Image Processing) – Toolkit from**
  - Rapid prototyping of image processing solutions
  - Includes large and extensible algorithm libraries
  - Graphical pipeline editor
  - Graphical user interface
Conclusion

Development of a white light interferometry application for the NPMM

- Based on a focus sensor measurement setup
- Precise height extraction by envelope or phase evaluation
- Skipping of large height differences by jumping to multiple defined pass-through ranges
- Stitching of adjacent measuring regions independent of topography
  - Determination of sensors orientation and scaling in advance by a measuring procedure
  - Correction of sensors tilt needs only a small overlap
Outlook

- Redesign of the measurement head
  - Zerodur base plate with sensor insertion apparatus
  - Sensor set-up made of Invar for inserting into the base plate
  - More high-grade compact microscope tube with higher magnification
  - Set-up for manual sensor aligning
This project is sponsored by the ministry of education and arts of the Free State of Thuringia (Germany) under the sign B 514-06 007

Thanks all those colleagues at the Technische Universität Ilmenau and the ZBS Ilmenau e. V., who have contributed to these developments

Thank you very much for your attention!