Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Metrology for virtual measuring instruments

VirtMet2025, Braunschweig, Germany, 3rd December 2025

Using virtual experiments for improving and evaluating the alignment and the measurement procedure in form measuring interferometry

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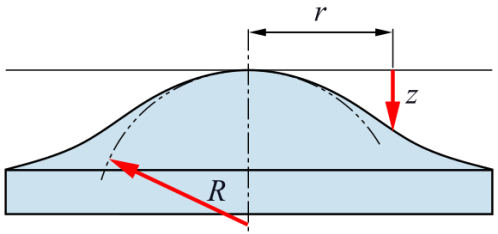
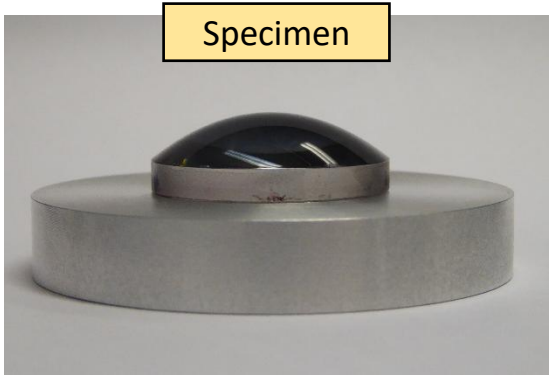
Form measurement of aspherical surfaces

Asphere

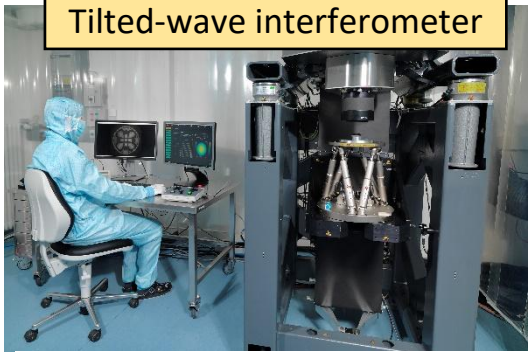


I, ArtMechanic (https://commons.wikimedia.org/wiki/File:Pfeilhöhe.svg), „Pfeilhöhe“, rotated + small form modification, https://creativecommons.org/licenses/by-sa/3.0/legalcode

Specimen

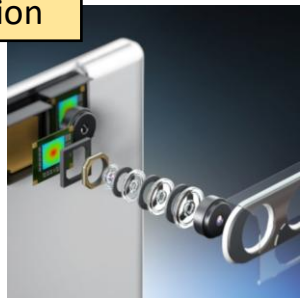


Tilted-wave interferometer



Miniaturization

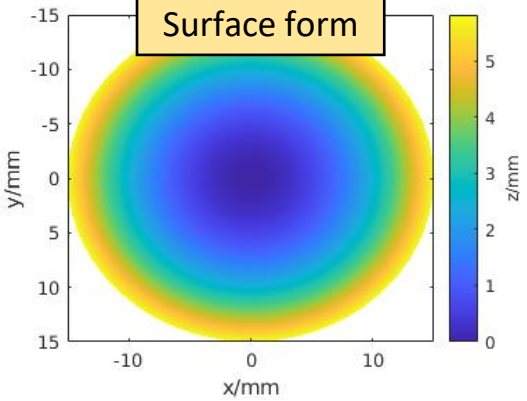
https://www.avmphoto.com/viltrox-56mm-f14-xf-lens-large-aperture-autofocus-portrait-compatible-with-sony-e-mount-cameras



https://www.schott.com/en-tw/products/optical-glass/applications

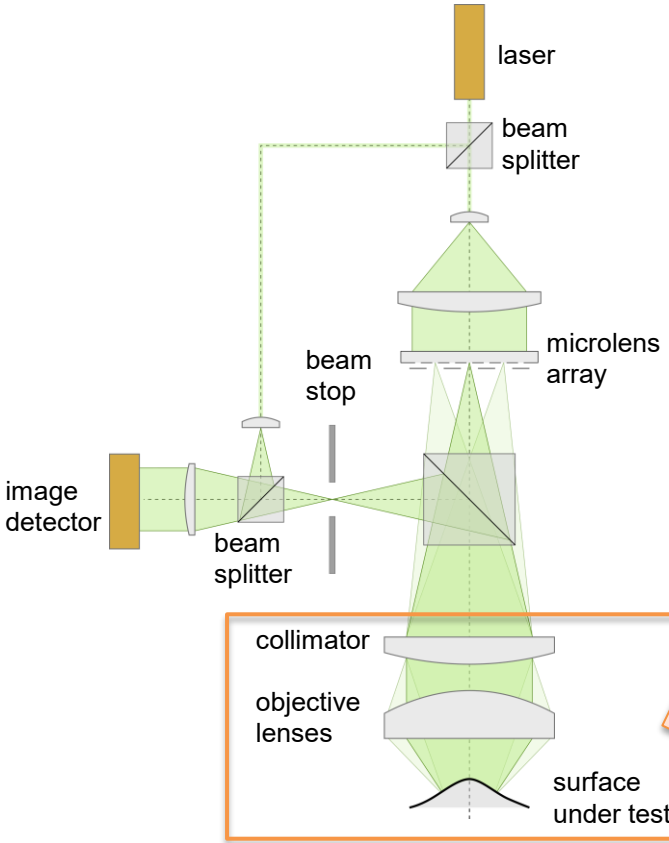
You can only manufacture as accurate as you can measure!

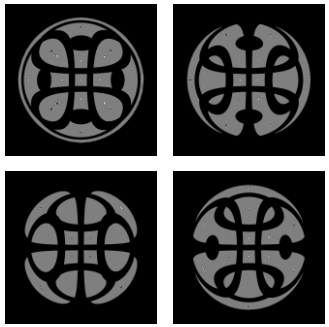
Surface form

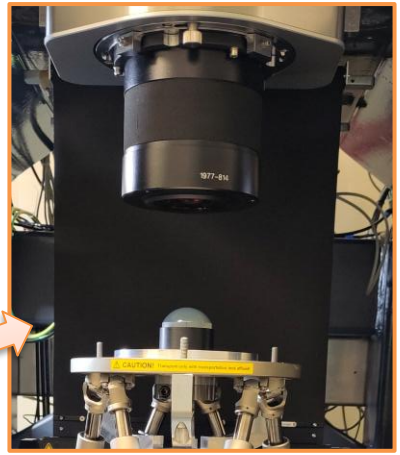


Schachtschneider et. al. *Measurement Science and Technology*, *29*(5), 055010.

Tilted-wave interferometer (TWI)







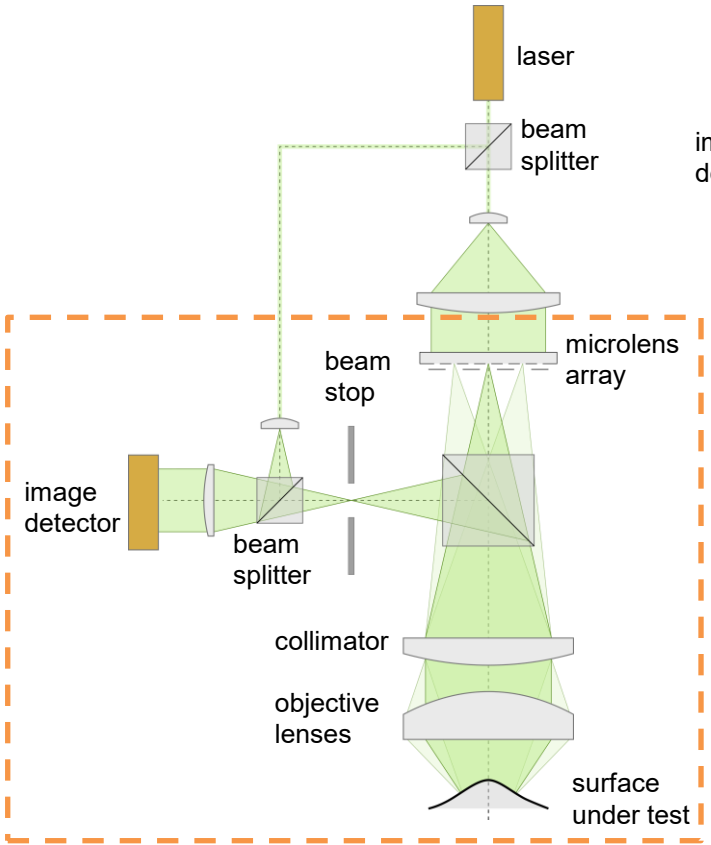
- Multiple measuring wavefront by microlens array
- Multiple interference patches
- Surface form retrieval by solving inverse problem

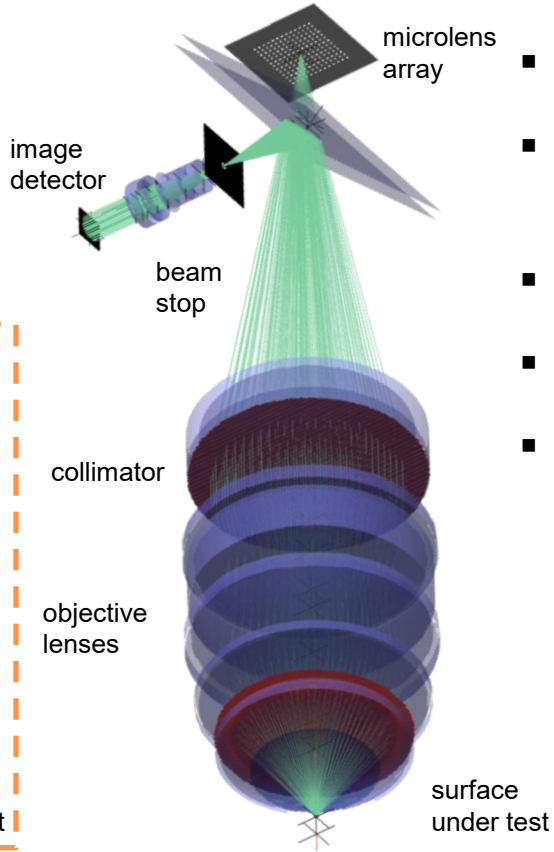
Measurement relies on accurate digital twin!

Invented by ito

J. Liesener, E. Garbusi, C. Pruss, W. Osten, “Verfahren und Messvorrichtung zur Vermessung einer optisch glatten Oberfläche,” DPMA Patent DE 10 2006 057 606.3 (2006)

Digital Twin: the Virtual TWI





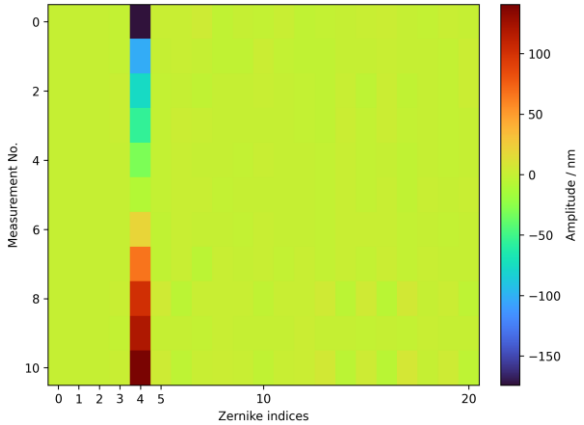
- Implemented in MATLAB
- Full ray-tracing and ray-aiming
- Using SimOptDevice
- Can generate interferograms
- Enables systematic investigations + can deliver derivatives

developed in cooperation with PTB WG 8.42

Powered by MATLAB

A real-life example

- Taking repeated measurements without repositioning
  → quantify stability of the setup
- 12 times in a row ca. 1 min apart



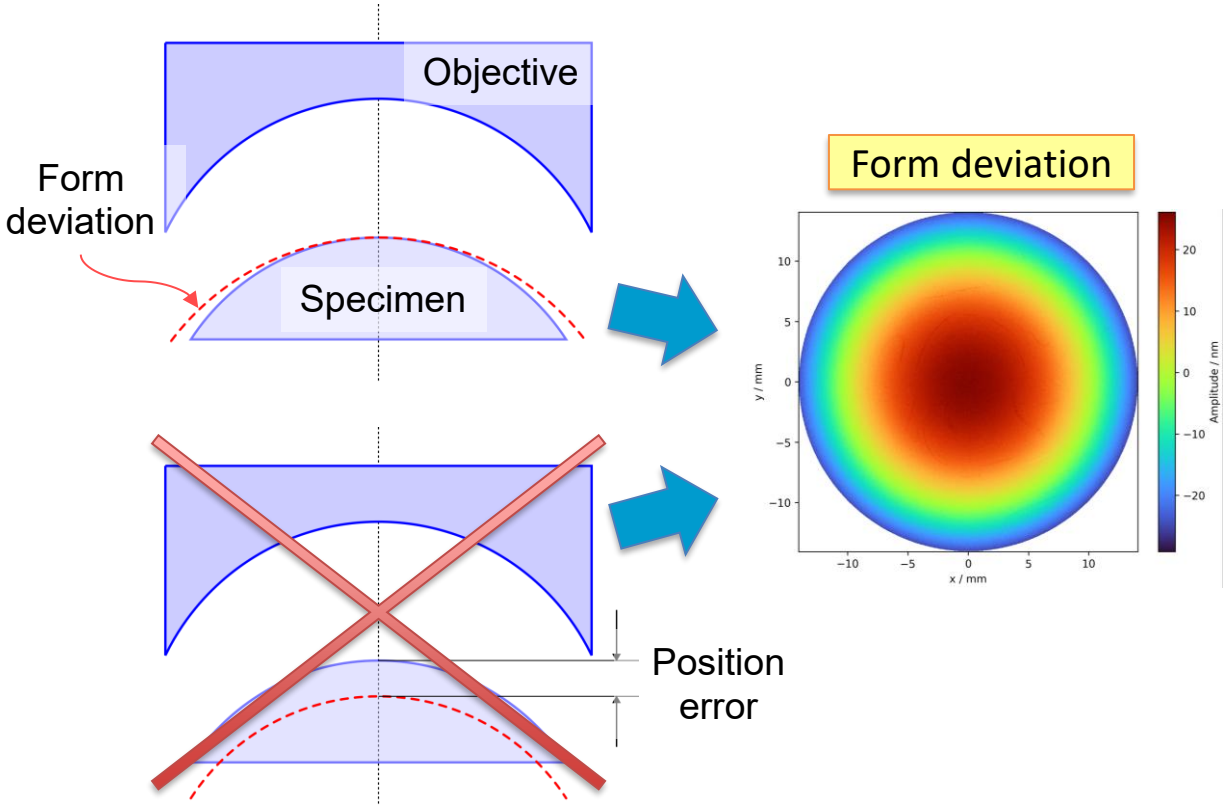
Alignment along optical axis

- **TWI measurement**:
  specimen in meas. pos.
  → interferograms
  → inverse problem
  → measurement result

- Specimen form deviation
  → measured form deviation

- Specimen position error
  → measured form deviation

Accurate specimen positioning necessary!



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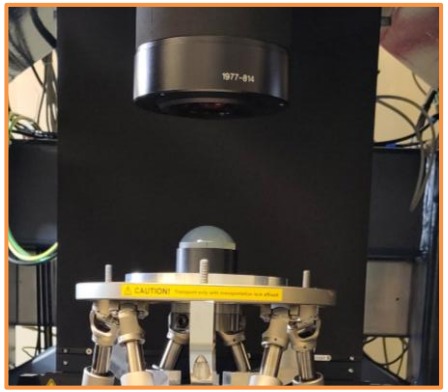
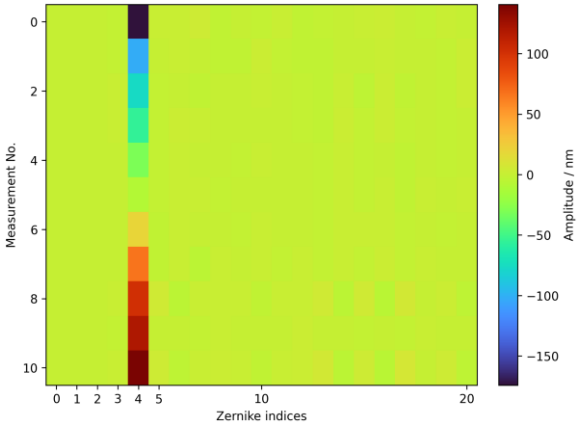
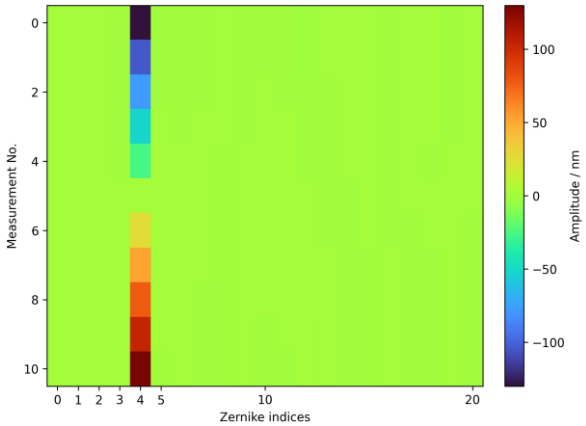
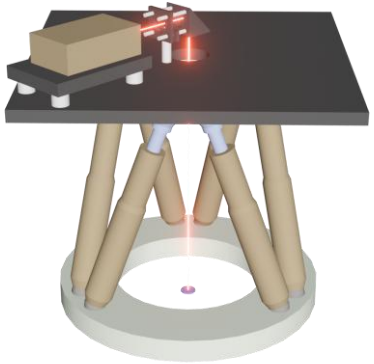




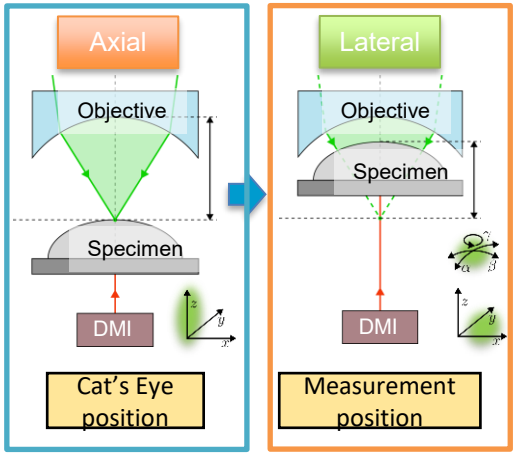


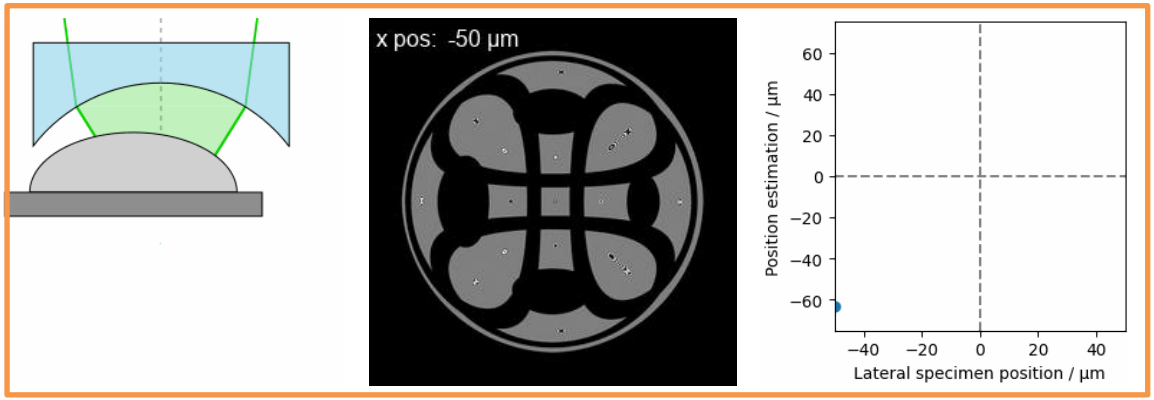


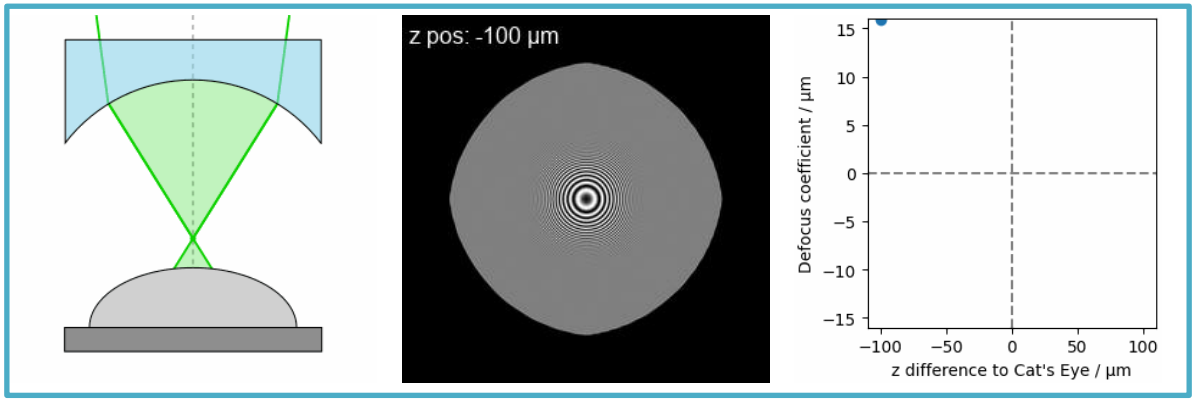
- Defocus is a hint for position offset
- ➢ Let's test influence with a virtual experiment
- Looks familiar
- Later drift measurement of hexapod confirms it!

Scholz, G., Evers, D., & Fortmeier, I. (2024), *Optics and Photonics for Advanced Dimensional Metrology III* (Vol. 12997, Issue 0, p. 42). SPIE.

Developing alignment strategy

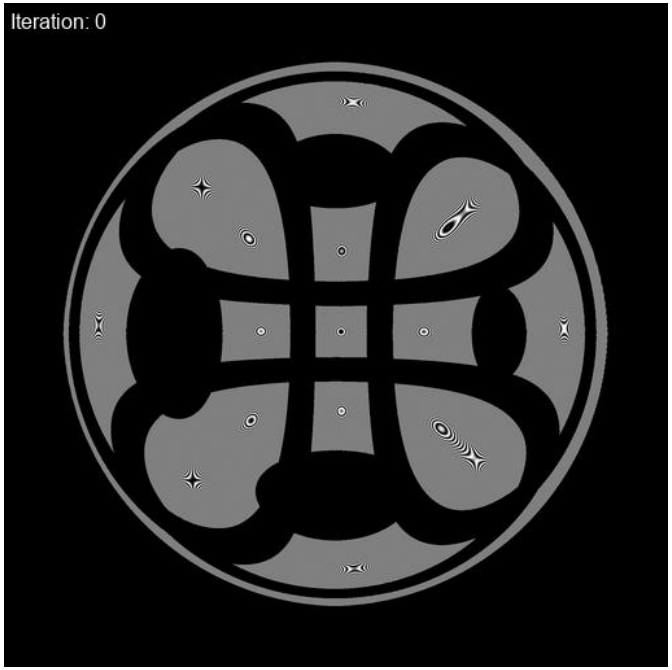


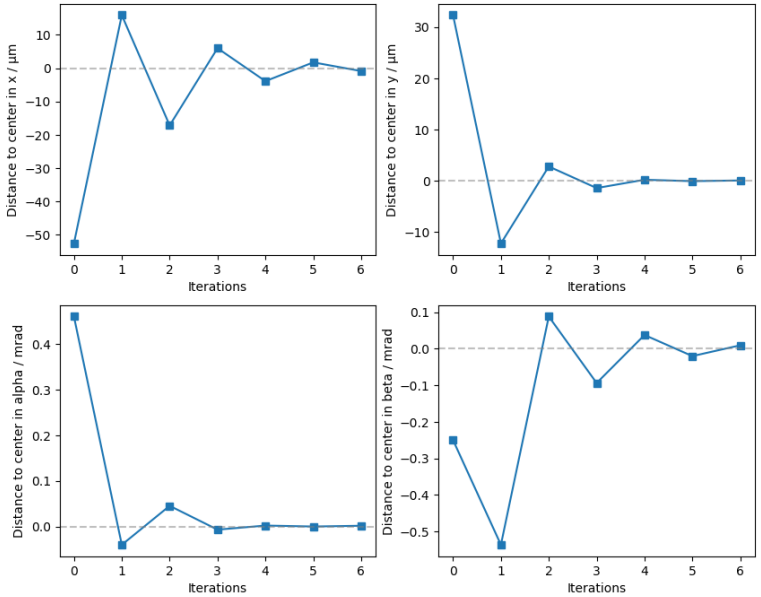




- Reference and data generation by simulation
- Using Defocus for axial alignment into Cat's Eye
- Linearized position estimation for lateral alignment

Testing lateral alignment

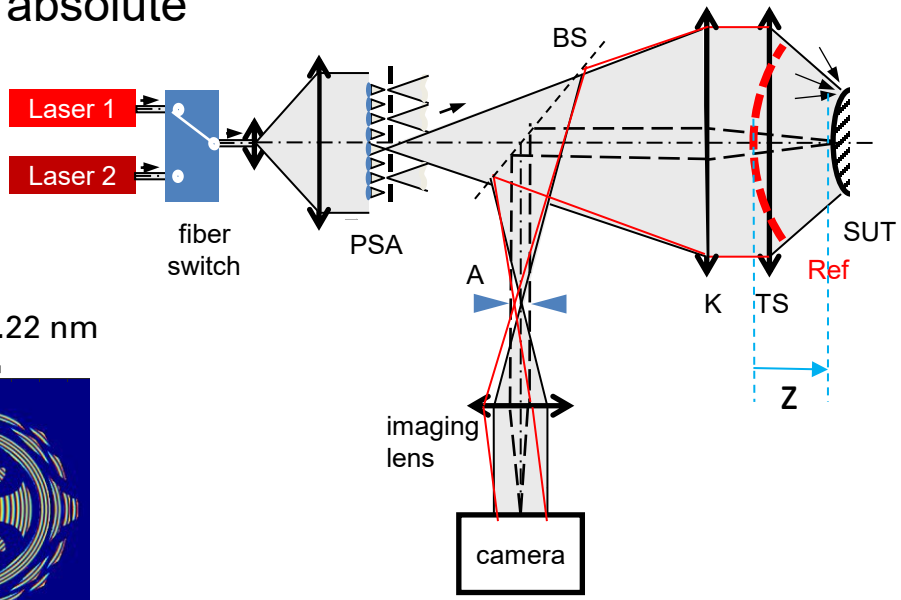




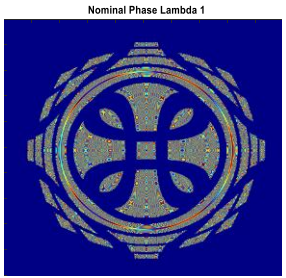
- Good convergence in few steps!

Fizeau TWI: patch offset & numeric stability

- Stability of Fizeau TWI offers chance for absolute distance measurement (phase offset)
- Multiple wavelength interferometry to assess fringe order



$\lambda_1 = 638.1361$ nm



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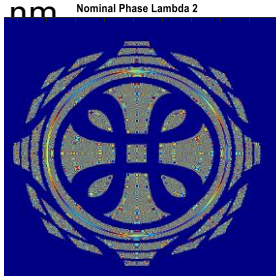
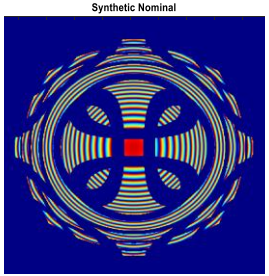
$\lambda_2 = 632.9976$ nm



$\lambda_{syn} = 78\,610.22$ nm



Virtual interferogram of a strong asphere (DEMA5) measured at two different wavelengths

Fizeau TWI: patch offset & numeric stability

Variant 1: Patch offset variation

Interferogram

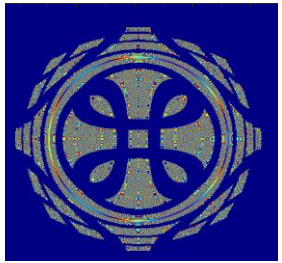
phase

Zernike form & **patch offset variation**

position estimation

High frequency error projection

SUT error



Variant 2: Known patch offsets

Interferogram

phase

Zernike form variation

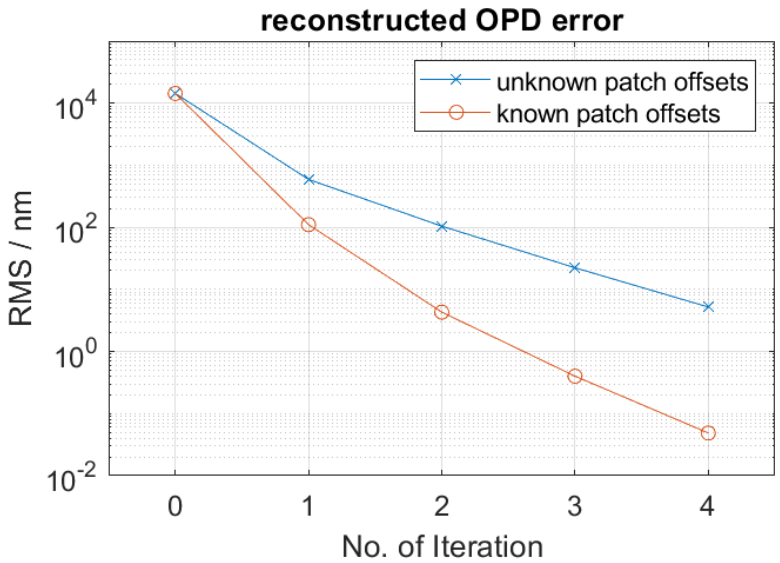
position estimation

High frequency error projection

SUT error

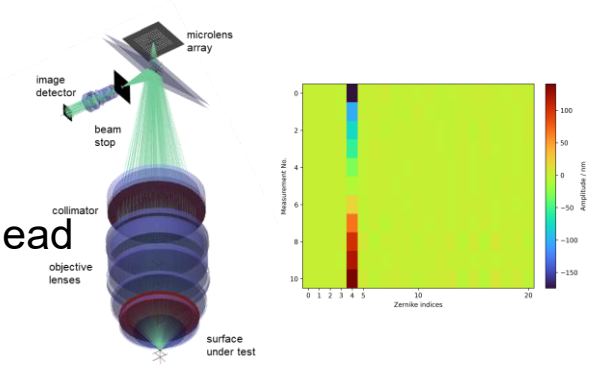
Fizeau TWI: patch offset & numeric stability

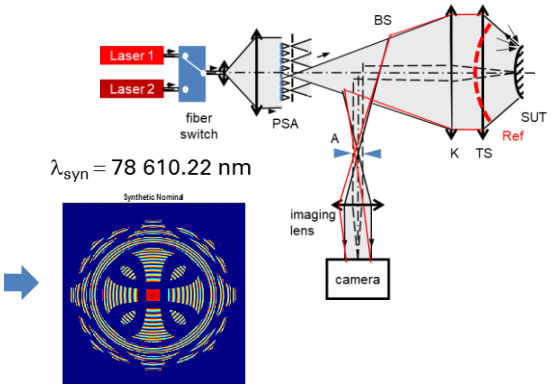
- Faster convergence
- More robust against algorithmic variations



Summary and Conclusions

- Tilted-wave interferometry relies on digital twin
- Difference between specimen position in model and experiment lead to reconstruction error
- Multi-step alignment strategy was developed using simulations
- Good convergence of specimen alignment
- Measuring patch offset (e.g. MWLI) increases numeric stability
  → developed with virtual experiments





Acknowledgement

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https://gepris.dfg.de/gepris/projekt/496703792?language=en

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