Single-shot Interferometry apart from zero position measurement

Kevin Treptow, Christian Schober, Christof Pruss, Alois Herkommer, Stephan Reichelt
Institute for applied Optics, University of Stuttgart
mailto:kevin.treptow@ito.uni-stuttgart.de

Single-shot interferometry provides measurements in highly disturbed environments. Using the light polarization and using a polarization-sensitive camera, all interferograms can be measured instantly and environment disturbances can be frozen.

1 Introduction

The phase shifting method in the field of interferometry is mostly implemented using piezo elements. The disadvantage of this phase shifting method is the long measurement time. The piezo element needs a certain amount of time during the recording of the individual interferograms to execute the mechanical movement. Therefore, the measurement accuracy highly depends on the measurement environment. Floor vibrations and air turbulence lead to large measurement uncertainties. Single-shot interferometry provides a remedy here. Using the light polarization and using a polarization-sensitive camera, all interferograms can be measured instantaneously. Therefore, the environment errors are suppressed. However, the spacial shift of the polarizer covered pixels in the camera-sensor leads to a systematic phase uncertainty for interferograms with high fringe densities. In the following chapters we will see how we can use the advantages of the single-shot sensor in an experimental setup. Furthermore we will present an approach to enhance the phase measurement certainty of the polarizing camera-sensor.

2 Experimental Setup

The single-shot interferometer is based on a Twyman-Green setup with a HE-NE-laser (λ= 633 nm) and with additional polarizing components [2]. The polarization camera contains a special micro grid polarizer in front of the CMOS sensor chip [1]. The polarizers with 0°. 45°, 90° and 180° orientation define a super pixel. One super pixel provides phase determination with one camera image.

3 Testing of astronomical mirrors

This setup is used to determine the surface error of an astronomical mirror with Ø =50cm and R=16m. The surface error is the deviation of the mirror surface from its perfect spherical shape. Due to the large distance between the mirror and the interferometer setup, the measurement took place in a strongly disturbed environment. Vibration errors are suppressed by single-shot measurements. Air turbulence can be mitigated by averaging a series of measurements (e.g. 1200 data sets). The surface error is shown in Fig. 2. Spherical Astigmatism and a strong dip in the center can be observed. The spatial pixel error and additional fabrication errors of the micro grid polarizer were neglected in this measurement. For low frequency fringe densities, these errors each lead to measurement uncertainties in the single-digit nano meter range.

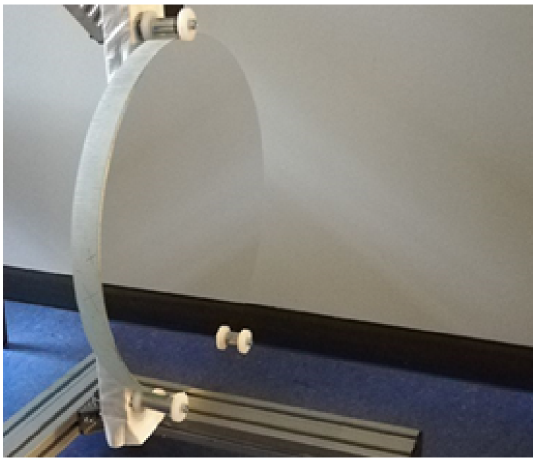

Fig. 1 *astronomical mirror with Ø =50 cm and R=16 m.*

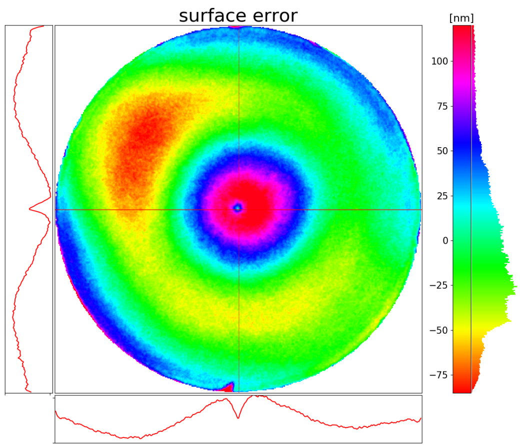

Fig. 2 *surface error of the astronomical mirror.*

DGaO Proceedings 2022 – http://www.dgao-proceedings.de – ISSN: 1614-8436 – urn:nbn:de:0287-2022-A029-3
submitted: 29.07.2022 – published: 05.09.2022

4 Spatial shift of camera pixels

Since the use of a polarization filter mask on the camera sensor reduces the resolution of the interferogram by a quarter compared to the well-known piezo phase shifting method, this leads to increased measurement uncertainty in high-frequency measurement images (see Fig. 3).

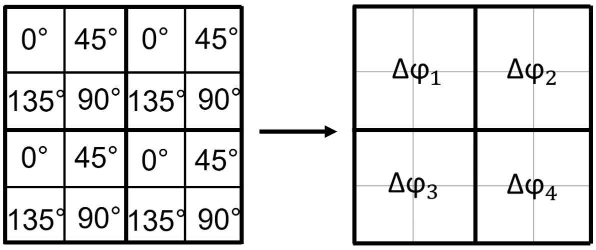

Fig. 3 *schematic representation of the inaccurate phase calculation* $\Delta\varphi$ *due to the spatial pixel shift.*

Subsequent interpolation of the intensity values in the interferograms using linear and sine algorithms can significantly improve phase determination. The linear interpolation is performed by averaging the neighboring pixel values. This approach decreases the phase calculation uncertainty below 1 nm for interferograms of up to 0.2 line pairs per pixel. However, next to the nyquist frequency the linear interpolation leads to large uncertainties. Therefore, the sinus interpolation is used. With the model based approach the fringe density can be estimated for all areas in the interferogram, provided the general surface shape is known (see Fig. 4). The intensity is described by a sinus fitfunction where the estimated fringe density will be used for an accurate fit.

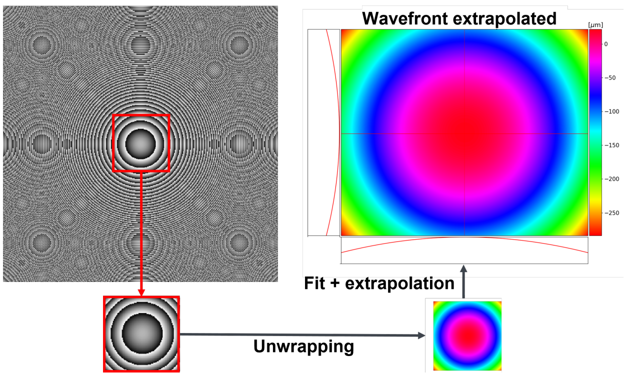

Fig. 4 *Model based approach to determine the fringe density in high frequently areas.*

Simulated data sets are used to compare the interpolated results with ideal data. The simulated surface represents a spherical mirror with a radius of curvature of 12 mm and an engraving with 100 nm depth. In Fig. 5 we see the difference between the phases of interpolated interferograms and their perfectly simulated values. Apart from global interpolation errors, the difference doesn't depend on the fringe density of the interferogramms as long as the general shape of the surface is sufficiently approximated. The average error is about 1 nm and at the edges of the engraving it's about 30 nm.

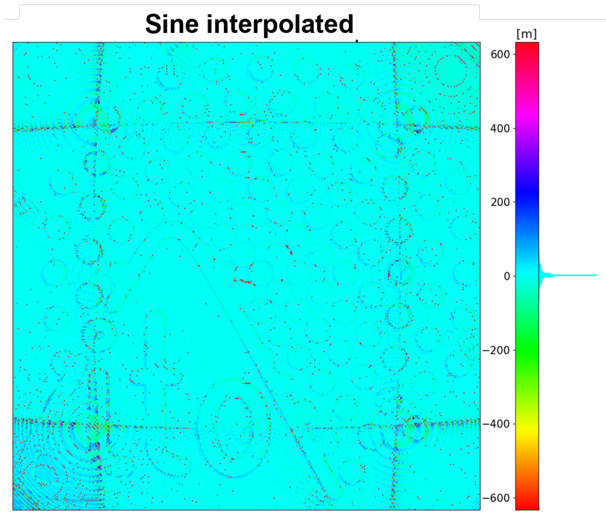

Fig. 5 *difference between phase, calculated by interpolated interferograms, and ideal phase without interpolation.*

5 Conclusion and Outlook

Using a polarizing sensitive camera for single-shot interferometry, the superpixel calculation leads to high phase uncertainties for interferograms with high fringe densities. By applying a linear interpolation algorithm to determine the missing intensity pixels, the phase determination can be improved. For fringe densities next to Nyquist, a sine interpolation is used with a model-based approach. This algorithm works independently of the fringe density. For better performance, an attempt is made to reduce the individual interpolation errors, which will improve the phase determination.

References

[1] Flyer: SONY Polarization Image Sensor IMX250MZR/MYR, IMX253MZR/MYR, 2019.

[2] James Millerd, Neal Brock, John Hayes, Michael North-Morris, Matt Novak and James Wyant,"Pixelated Phase-Mask Dynamic Interferometer", Proceedings of SPIE Vol. 5531, 2004