Characterization of wavefront phase sensors by using a piezoelectric deformable mirror with nanometric steps

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Abstract

Wooptix is developing light-field technologies for advanced imaging solutions which will provide superior measurement technology, also in challenging situations such as the modelling of transparent objects. For this, good knowledge of wavefront structure is required, hence our current work on wavefront sensing.

The characterization process of a Wavefront sensing (WFS) device is not standardized; there are many factors that affect the feasibility of the process. We propose a well-defined procedure to estimate the behavior of the WFS by using a piezoelectric deformable mirror (DM). Several factors depend on the sensor configuration, such as wavelength, sensitivity, accuracy, precision, and dynamic range. This study demonstrates how to utilize the steps of deformable mirrors to characterize different WFS and estimate the standard deviation of the materials under study, in this case, the DM variability. This approach enables standard users to define the correct WFS for each use case and allows characterizing subsequent elements by understanding the potential deflections caused by the WFS.

Introduction

There are many devices available for estimating the wavefront of an object, as depicted in Figure 1. Each device comes with specifications that assess its suitability for the final use case. However, the process of obtaining these specifications is not well-defined by manufacturers, and the procedure provides details on how to adapt them for various applications.

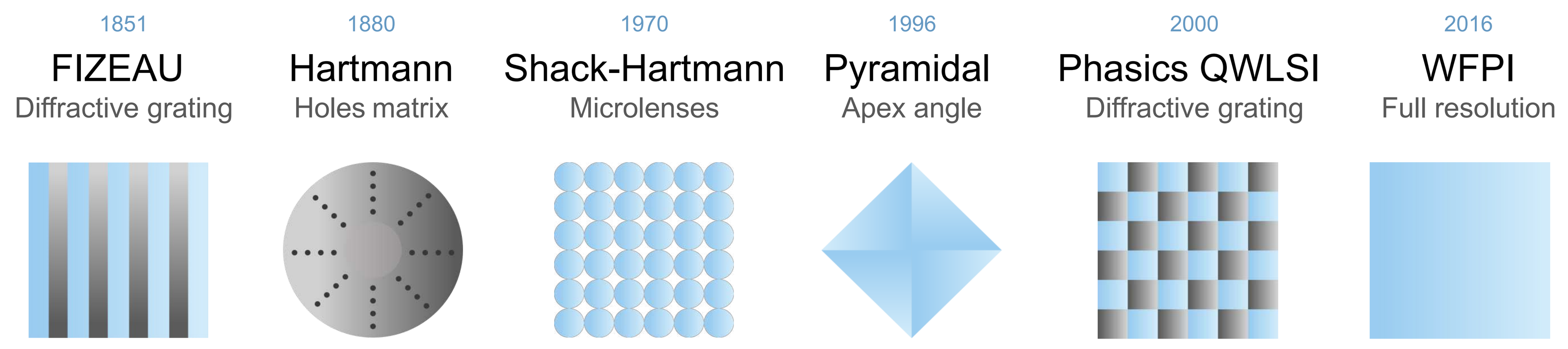


Figure 1. Different WFS types. Some Figures are inspired by [3]

This study outlines a procedure for characterizing a wavefront sensor using a piezoelectric deformable mirror (DM), assessed using two sensors: the Shack-Hartman (SH) sensor [1] and our WFPI sensor [2].

Material & methods

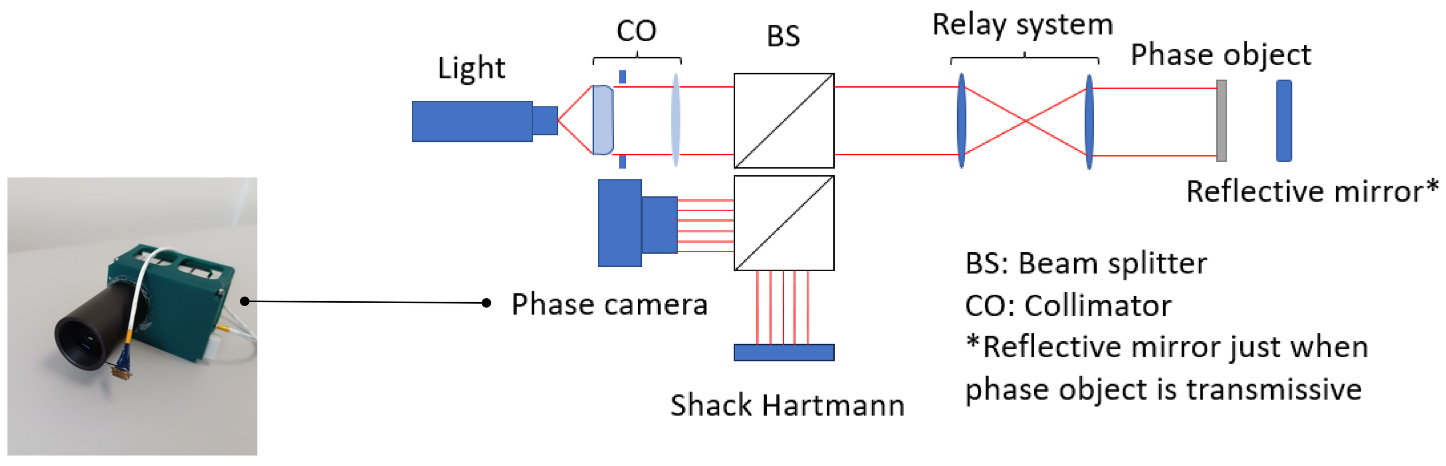


Figure 2. Experimental setup.

Parameters to define a wavefront sensor

Parameter	Description
Wavelenght	Type of light source to be used
Aperture dimensions	Maximum object size that can be accommodated
Spatial resolution	Minimum lateral size detectable
Sampling	Number of information points collected
Accuracy	Deviation from the real measurement
Precision	Variation between multiple measurements
Dynamic range	Range of object heights that can be measured

Evaluation metrics:

- Peak to Valley
- Root mean square

Assumptions: median difference to determine the minimum stroke, 0.185 is a 5% of error of the DM which is characterized.

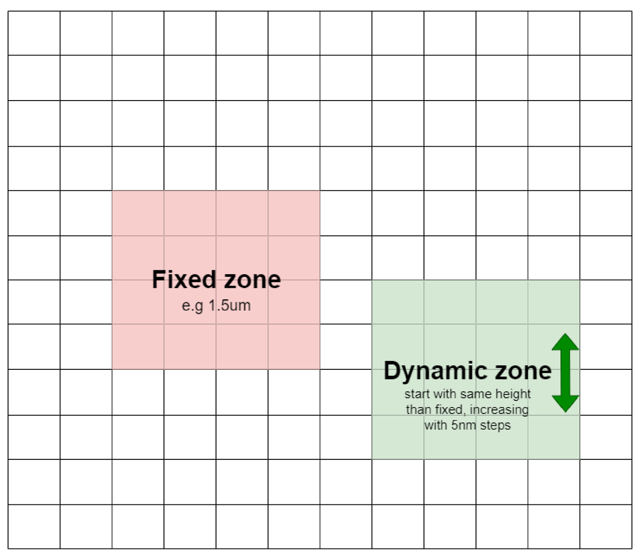
$$H_0 = \frac{|\mu_0 - \mu_1|}{\mu_0 + \mu_1} \leq 0.185$$

$$H_1 = \frac{|\mu_0 - \mu_1|}{\mu_0 + \mu_1} > 0.185$$

Where:

- μ_0 DM mean
- μ_1 Sensor mean

Datasheet example



Wavefront Measurement			
Wavefront Accuracy 3)	λ/30 rms @ 633 nm		λ/60 rms @ 633 nm
Wavefront Sensitivity 4)	λ/100 rms @ 633 nm		λ/200 rms @ 633 nm
Wavefront Dynamic Range 5)	> 100 λ @ 633 nm		> 50 λ @ 633 nm
Wavefront Slope 6)	max. ± 1.0 °	max. ± 0.8 °	max. ± 0.5 °
Local Wavefront Curvature 7)	> 7.4 mm	> 10.0 mm	> 40.0 mm
Microlenses			
Microlens Array	MLA150-5C	MLA150-7AR	MLA300-14AR
Substrate Material	Fused Silica (Quartz)		
Wavelength Range	300 to 1100 nm	400 to 900 nm	400 to 900 nm
Lenslet Pitch	150 µm		300 µm
Lens Diameter	146 µm		295 µm^2
Max. Number of Lenslets	47 x 35		23 x 17
Number of Active Lenslets	Software Selectable		
MLA Aperture Size	Ø 9.0 mm		

The proposed method allows to define all the parameters depicted in the table, using a conventional DM. The hypothesis contrast determines the stroke using an α of 5%, which is the estimated error.

Results

Multiple 2x2 piston heights for each sensors.
This experiment allows to characterize the minimum height detectable.

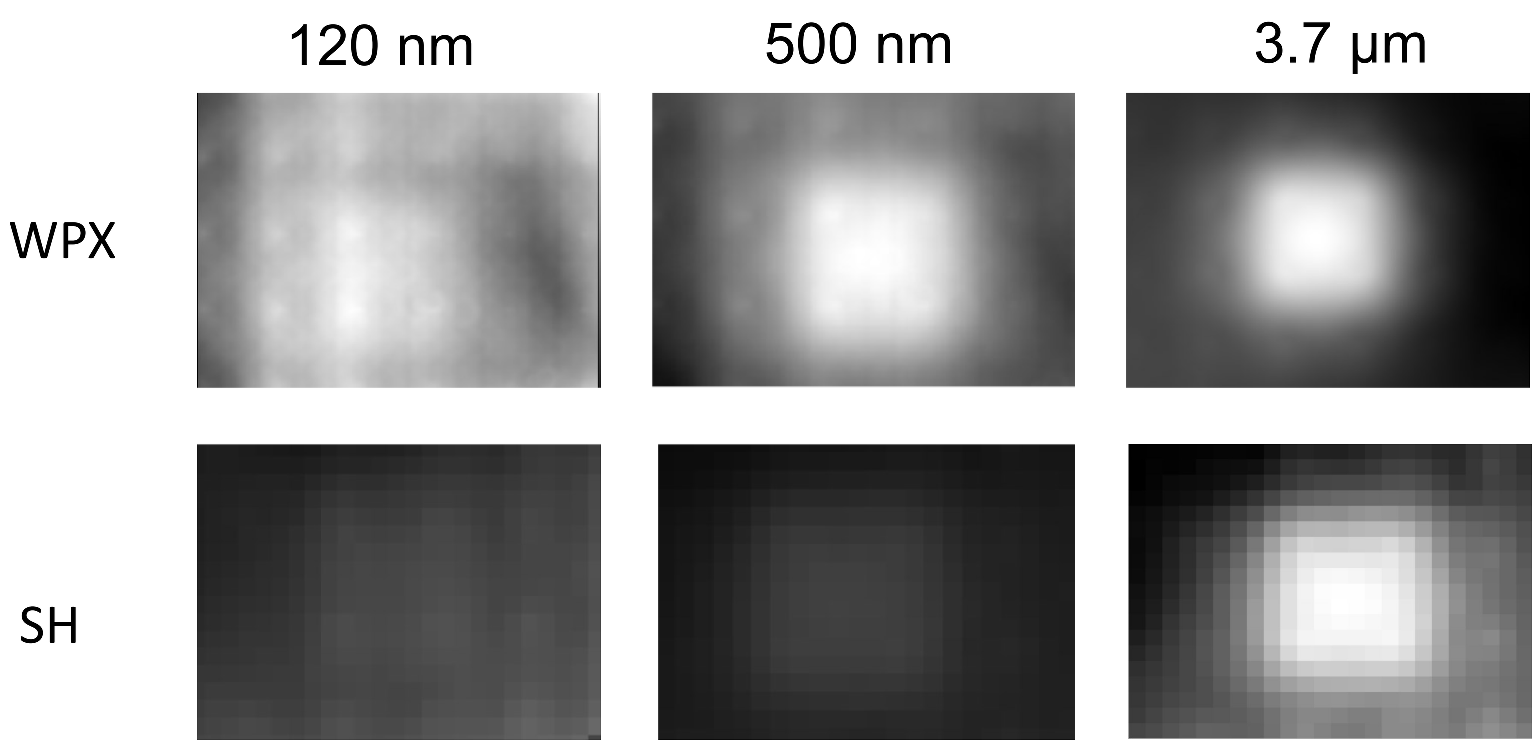
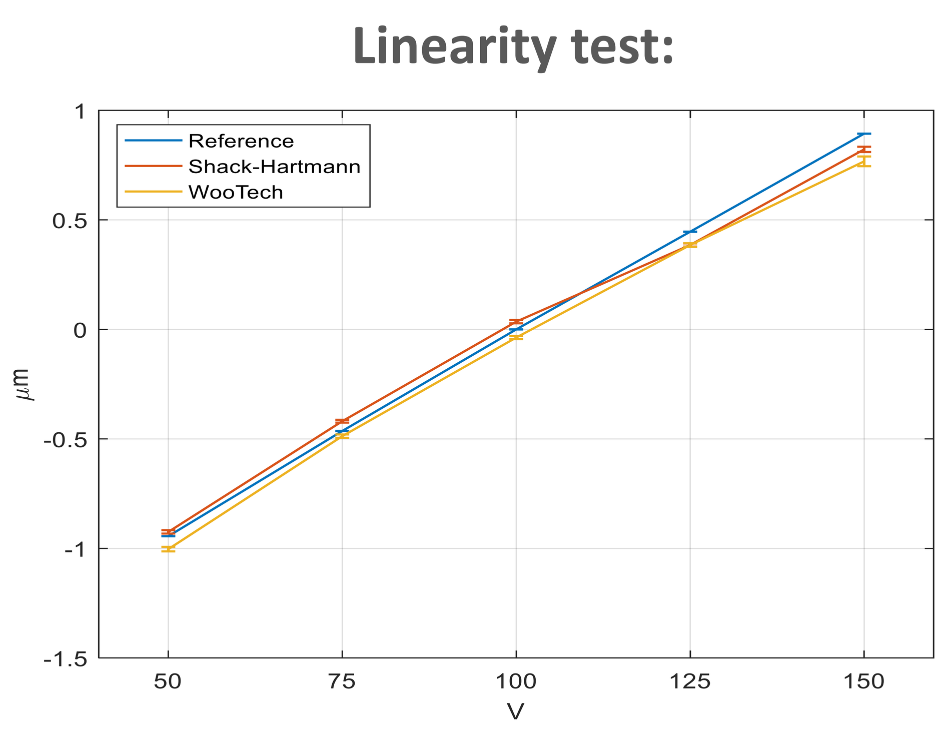


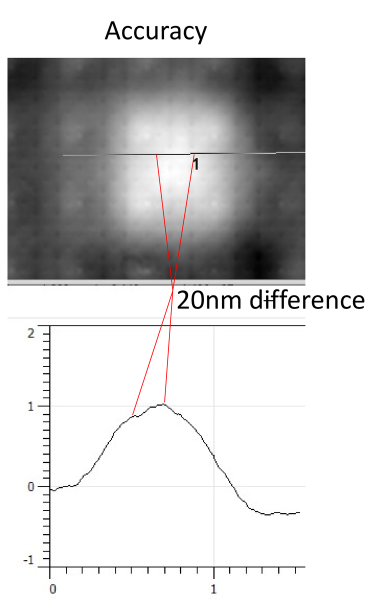
Figure 4. Multiple piston heights with the sensors used in the experiment.

A linearity test detects the adjustment to the manufacturer characterization.



	Wooptix	SH
R^2	0.9996	0.9974

Minimum gap detectable (accuracy) by Wooptix's phase camera.



	Wooptix	SH
Accuracy	25 nm (RMS)	34 nm (RMS)
Precision*	9 nm (RMS)	15 nm (RMS)

* Precision test taken under the same conditions with 100 images

Conclusions

- This study illustrates the testing process for different wavefront sensors, allowing to assess the metrics under consistent conditions.
- To evaluate the sensors adaptability to a range of use cases, is essential to include detailed test specifications within the documentation.
- Both sensors were successfully characterized reaching in the Wooptix camera case a **25 nm** accuracy and **9 nm** precision, and **34 nm** accuracy and **15 nm** repeatability for the Shack Hartmann sensor.

References

1. Hartmann, J. (1904). "Objektivuntersuchungen". Zeitschrift für Instrumentenkunde. Berlin: Verlag von Julius Springer. 24: 1–25, 33–47, 97–117.
2. Oliva-García, R.; Cairós, C.; Trujillo-Sevilla, J.M.; Velasco-Ocaña, M.; Rodríguez-Ramos, J.M. Real-Time Wavefront Sensing at High Resolution with an Electrically Tunable Lens. *Sensors* **2023**, *23*, 6651. https://doi.org/10.3390/s23156651
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