Experimental Determination of Zernike-coefficients based on measured Edge Spread Functions

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The algorithm for determination of Zernike-coefficients based on Line Spread Functions presented and theoretically tested in [1] is extended for the use of Edge Spread Functions (ESFs). First results with real measurement data are presented for two different objectives.

1 Introduction

A quantitative analysis of aberrations, for example by Zernike decomposition of an aberrated wavefront, is usually done by interferometric measurement [2]. Since these measurements are quite complex, we aim for a simple and fast method based on the experimentally easily accessible ESF. This also opens up the use of this method as a production-related tool for assessing the production status of optical systems.

The development of the algorithm based on measuring the ESF and first theoretical simulations with artificial measurement signals from the optics simulation program OSLO is demonstrated in [1].

2 Methods

In contrast to the first version the algorithm has been modified that we now integrate the LSF for forming a variable ESF signal for fitting to the measurement signal.

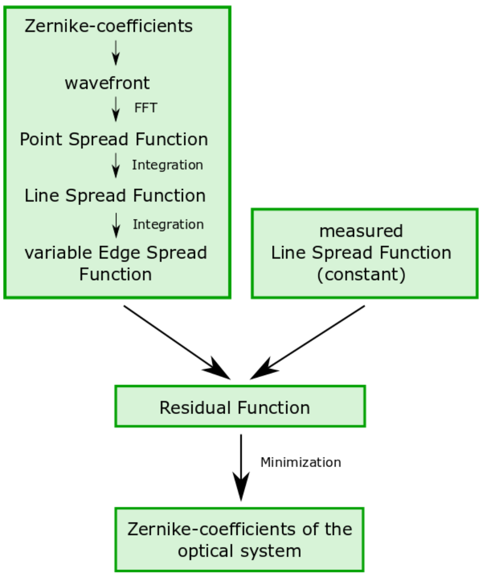

Fig. 1 *Illustration of the program run.*

It has to be mentioned that with the described method it is not possible to determine the first Zernike-coefficient (Piston) since it is just a constant added to the wavefront.
To achieve sub-pixel resolution, we use a *Slanted Edge* algorithm to process two images of a vertical and a horizontal edge under a slight angle with respect to the according axis. They are taken with the objective that we want to evaluate. Image errors of the tube lens can be neglected because this lens is very well corrected.
The edge is formed by a frosted glass target with vapor-deposited aluminum. It shows a L-like structure. Possible irregularities of the target are weakened by the slanted edge algorithm.
We tested two different objectives, a microscope objective and a triplet with a 3D printed housing (for further information on the 3D printing process see [3]).

3 Results

Table 1 shows the Zernike-coefficients 5 (X Astigmatism), 6 (Y Astigmatism), 7 (X Coma), 8 (Y Coma) and 9 (Spherical) from our algorithm and from interferometric measurements for the microscope objective, and the deviation between these two. We limit ourselves to present these coefficients, since they are the most relevant coefficients to judge the image quality of an optical system during the manufacturing process.

Coeff. Nr	Algorithm	Reference	Δ in λ
5	-0.0210	-0.0302	9.2e-3
6	-0.0766	-0.0708	5.8e-3
7	-0.0787	-0.0224	5.6e-2
8	-0.0959	0.0091	0.105
9	-0.0216	-0.0169	4.7e-3

Tab. 1 Microscope objective*: Comparison of the results from our algorithm with interferometric measurements (Fringe scheme).*

The difference for the coefficients 5,6 and 9 are less than λ/100, since Zernike-coefficients are measured in units of wavelengths. The coefficients for coma show a larger deviation. *figure 2* and *figure 3* show the measured ESF(blue), the calculated ESF based

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on the fit of our algorithm (orange) and the calculated ESF based on interferometric data (yellow).

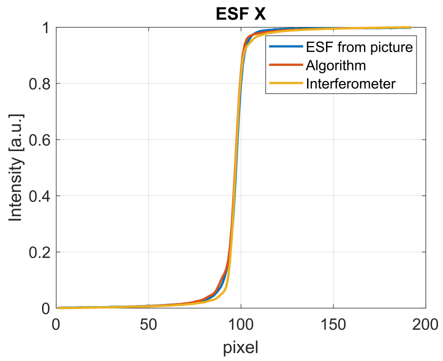

Fig. 2 *Comparison ESF in x-direction for microscope objective.*

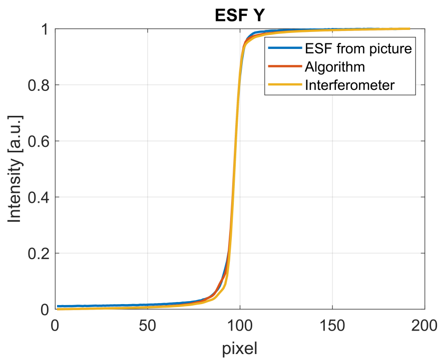

Fig. 3 *Comparison ESF in y-direction for microscope objective.*

The curves from the measured ESF signal and the calculated ESF based on the fit of our algorithm correspond very well, while the curves based on the Zernike-coefficients characterized by interferometric measurement differ in the regions of the rising edge and saturation. Further investigations are necessary to analyze these differences.

The results for a triplet with a 3D printed housing are shown in *table 2*. The Zernike-coefficients are relatively high due to suboptimal mounting, caused by the 3D printed holders.

Coeff. Nr	Algorithm	Coeff. Nr	Algorithm
1	(0)	6	0.7016
2	-0.483	7	-0.1614
3	-0.2866	8	-0.00426
4	0.3118	9	-0.1393
5	-0.2064		

Tab. 2 Triplet*: Zernike-coefficients calculated from measured ESFs (Fringe scheme).*

This system demonstrates the reliability of the algorithm, even for strong aberrated wavefronts. It is obvious that the algorithm can adapt the measurement signal very well.

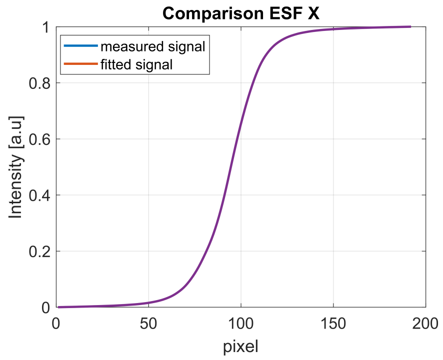

Fig. 4 *Comparison ESF in x-direction for the triplet.*

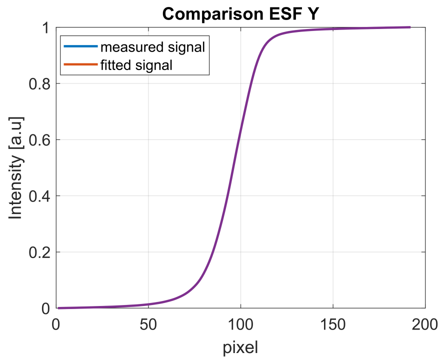

Fig. 5 *Comparison ESF in y-direction for the triplet.*

4 Discussion

The functionality of the algorithm was demonstrated based on measured edge image functions for two lens systems. Adaptation of the measurement signal based on variable Zernike-coefficients works very well. Comparison of the resulting Zernike-coefficients from our algorithm are largely congruent with interferometric measurements, with a deviation of only $\lambda/100$ except for the coefficients for primary coma.

Even with discrepancy between ESF and interferometric measurements, it could be stated that the algorithm works well to figure out the main aberrations which are responsible for image quality loss during a manufacturing process.

References

[1] S.Krämer, C. Butka and T.Sure, "Determination of Zernike-coefficients based on Line Spread Functions," Proc. DGaO, p. A37 (2020).

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[3] C.Butka, S.Krämer and T.Sure, "Cost efficient 3d printed lens mounting, an alternative for prototyping," Proc. DGaO, p. P24 (2020).