Determination of Zernike-coefficients based on Line Spread Functions

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A new method for determination of Zernike-coefficients of an optical system based on the signal of Line-Spread-Functions is presented. It was possible to determine the first eight Zernike-coefficients of different lens systems within a theoretical simulation. To model the Line Spread Functions which are analyzed by the described method the optics simulation program OSLO was used.

1 Introduction

To quantitatively investigate misalignments and tilts of lenses, which are the main reason for coma, interferometric measurements are common [1]. In these measurements wavefront reconstruction is done by fitting a set of Zernike-polynomials. With the Zernike coefficients the aberrations are evaluated [2, 3]. Often the needed interferometric setup is not available for some users.
This is the reason why we want to develop an efficient way to judge the quality of production of an optical system using a typical imaging method. For this purpose a MATLAB-algorithm which calculates the Zernike-coefficients based on measured Line Spread Functions is developed.

2 Methods

The final method will be based on a measured Line Spread Function.
We start with a simulated Line Spread Function which will be fitted to the measured signal. A MATLAB-function calculates the related Line Spread Function from given Zernike-coefficients. By fitting this signal to the measured data the Zernike coefficients of the optical system are determined. The structure of the program is shown in *figure 1*.
Based on the given Zernike coefficients the image of the wavefront is calculated. By Fourier transformation of the complex amplitude of the wavefront the Point Spread Function (PSF) is obtained, Integration of the PSF leads to the Line Spread Function (LSF) in x- and y-direction.
The second signal is the measured LSF. The function described above aims to fit to this data.
With these two signals a residual function is built to vary the Zernike-coefficients.
The residual function is passed to the MATLAB-built-in Downhill-Simplex *lsqnonlin* based on a Levenberg-Marquardt algorithm. To start it, we generate a set of random seeds. These contain the values -0.05,0 and 0.05. All combinations for the first eight Zernike-coefficients are calculated. These start values are passed to the algorithm inside of a loop.
The minimal residual after the fitting procedure determines the corresponding Zernike-coefficients. An educated guess for the start values of the Zernike-coefficients help to reduce the computation time a lot.
With this method we will not be able to determine the first Zernike coefficient, it is just a constant added to the wavefront. Therefore, it can be neglected.

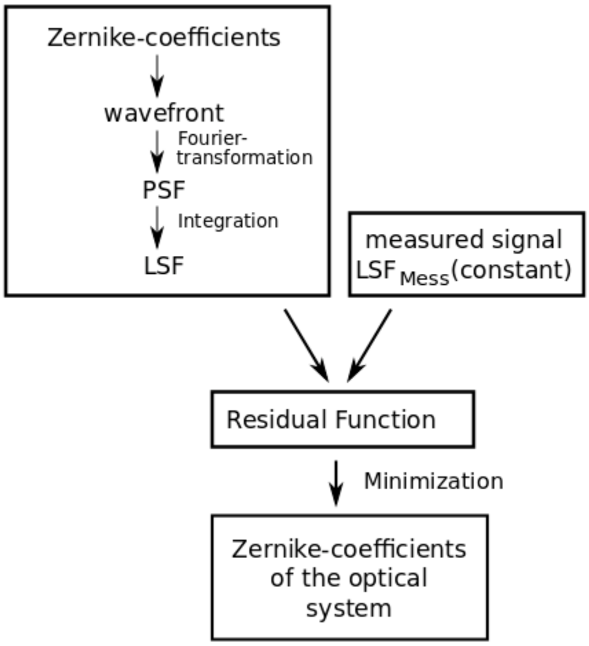

Fig. 1 *Illustration of the program run.*

To generate the theoretical Line Spread Function signals which will work as a virtual measurement signal, the optics simulation program OSLO is used. Two different lens systems, shown in *figure 2* and *figure 3*, were used to obtain the data. We take the Demo-Triplet from the OSLO database and implemented a decenter to the center lens of 0.01mm in x- and y-direction to generate coma.
We only calculate the first eight Zernike-coefficients since these are sufficient in a first step of adjustment.

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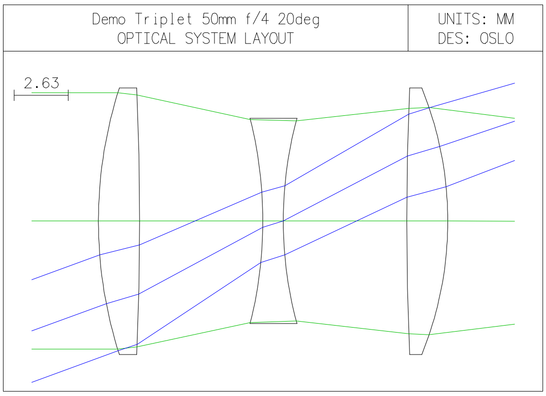

Fig. 2 *Triplet with decenter of the middle lens of 0.01 mm in x- and y-direction.*

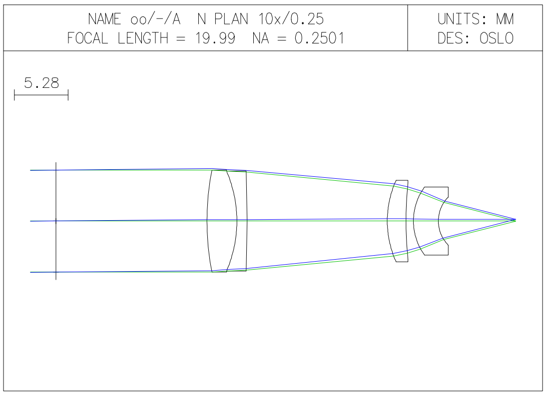

Fig. 3 *Microscope objective illustrated by* OSLO.

3 Results

A second system, a microscope objective, was also created with OSLO and the LSF was computed.
Based on these signals the first eight Zernike-coefficients of the lens systems were determined by analyzation of the LSF with the MATLAB-algorithm described above. The results are shown in table *1* and table *2*.

Coefficient Nr	OSLO	MATLAB
0	-0.123405	0.0000
1	-0.006471	-0.006515
2	-0.006471	-0.006516
3	0.009305	0.0000
4	0	0.0000
5	0.001197	0.0000
6	0.148566	0.148765
7	0.148566	0.148831

Tab. 1 Demo-Triplet*: comparison of the results from* MATLAB *with the given Zernike-coefficients from* OSLO *(Fringe scheme).*

Coefficient Nr.	OSLO	MATLAB
0	-0.010462	0.0000
1	0	0.0000
2	0	0.0000
3	0.005486	0.005436
4	0	-0.0001
5	0	0.0000
6	0	0.0000
7	0	0.0000

Tab. 2 Microscope objective*: comparison of the results from* MATLAB *with the given Zernike-coefficients from* OSLO *(Fringe scheme).*

We are not able to determine the first coefficient, which describes the offset, since the algorithm uses the difference of the two signals for minimization. Therefore, the first one is neglected.

4 Discussion

The Zernike coefficients calculated by our MATLAB-algorithm show only small deviations from the given coefficients from OSLO. We need to investigate the reason of the deviations, whether they are caused by using only the first eight Zernike-coefficients or if the program just needs more time to compute the Zernike-coefficients more precise.
We do not have any knowledge whether the algorithm found a global or local minimum. There is also no guarantee that the global minimum is found with the given seeds. Therefore, it is important to always check and interpret the results. A good way to investigate the quality of the results is to compare the measured and fitted Line Spread Functions. If they show only small deviation the calculated Zernike-coefficients represent the optical system well. The algorithm will fail if there are a lot of higher order aberrations, because they influence the values of the lower order coefficients.
Tests with data from real measurements are pending.

References

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