QUALITY ASSESSMENT OF FOCUSING OPTICS BY ABERRATION RETRIEVAL USING THE EXTENDED NIJBOER-ZERNIKE DIFFRACTION THEORY

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In a recent publication [1] the authors have presented a formalism that, starting from the complex field in the entrance or exit pupil of the optical system, enables an accurate forward calculation of the field in the focal region produced by a high-numerical aperture beam, including the vectorial aspects. The analysis is an extension of the original Nijboer-Zernike theory of aberrations and is capable of representing the field vectors in the focal region of a high-*NA* objective with the aid of a well-converging series expansion in Bessel functions.

In this presentation we will discuss the inverse problem, viz. the reconstruction of the complex field in the exit pupil by collecting a set of through-focus intensity measurements. Once the complex field distribution in the exit pupil has been reconstructed, it is possible to retrieve the amplitude and phase transmission function of the imaging optical system, e.g. of a microscope objective or a high-quality projection lens.

For the scalar diffraction case, the starting point is the semi-analytic result for the diffraction integral, yielding the following expression for the complex amplitude in the focal volume,

$$U(r,\varphi,f) = 2V_0^0(r,f) + 2\sum_{n,m} i^m \beta_n^m V_n^m(r,f)\exp(im\varphi) \ , \tag{1}$$

and the approximated expression for the intensity according to

$$I(r,\varphi,f) \approx 4\left|V_0^0(r,f)\right|^2 + 8\sum_{n,m}\mathrm{Re}\left\{i^m \beta_n^m V_n^m(r,f)V_0^{0*}(r,f)\exp(im\varphi)\right\} , \tag{2}$$

which is valid when the amplitude variations and aberrations introduced by the optical system are small; r, f, and φ are the cylindrical co-ordinates in the focal region and β_n^m (in general complex-valued) are the Zernike coefficients describing the amplitude and phase distribution of the field in the exit pupil according to $A(\rho,\vartheta)\exp\{ikW(\rho,\vartheta)\} = \sum \beta_n^m R_n^m(\rho)\exp(im\vartheta)$.

In Eqs. (1) and (2), we use the analytic functions $V_n^m(r,f)$, see Ref. (1), that describe the contribution to the field distribution in the focal volume associated with a particular 'aberration' coefficient β_n^m in the exit pupil. Selecting a large number of positions (r_l,φ_l,f_l) in the focal volume, Eq.(2) can be developed into a set of linear equations in the unknown coefficients β_n^m and this set can be solved in a relatively straightforward manner. In the presentation we will further discuss the extra complications that arise when the fully vectorial situation is treated in the case of high-NA imaging.

1. J.J.M. Braat, P. Dirksen, A.J.E.M. Janssen, A.S. van de Nes, "Extended Nijboer-Zernike representation of the vector field in the focal region of an aberrated high-aperture optical system", J. Opt. Soc. Am. **A 20**, 2281-2292 (2003)