

Numerical Models for Speckle Fields

Thomas Meinecke*, Damien P. Kelly**, Stefan Sinzinger*

**Fachgebiet Technische Optik, Institut für Micro- und Nanotechnologien, Technische Universität Ilmenau*

***Fachgebiet Optik-Design, Institut für Micro- und Nanotechnologien, Technische Universität Ilmenau*

<mailto:thomas.meinecke@tu-ilmenau.de>

Speckles appear as noisy steady light patterns caused by random phase disturbance of coherently propagating light. Their suppression and use in optical metrology make its simulation and evaluation necessary. This contribution addresses the issue of numerical propagation of speckle distributions.

1 Introduction

When we work on a practical setup in our lab with coherent light, grainy steady patterns, called speckles, appear. They are caused by light straying either on rough surfaces or within scattering volumes or can be generated synthetically by spatial light modulators. They are noisy, random light distributions and can be evaluated statistically. Therefore they are applied as test distributions in metrology, i.e. shearing interferometry, measurements of vibrations and rotations, visualization of aberrations and phase retrieval. If a speckle field is captured by a camera one gets an intensity image. Because of its noise, i.e. random characteristics statistical evaluation can be done as follows: either in a histogram where the counts for each intensity value are plotted and can be fitted to a special probability density function PDF, or by calculation of the autocorrelation function, which contains the information of the correlation length, i.e. the average speckle size ASS . The digital generation of complex amplitude $U(N,M)$ of speckle distributions is performed by adding two sets of random, Gaussian distributed numbers; one set represents the real and the other the imaginary part, the intensity is then calculated by the multiplication of its complex amplitude times its complex conjugate [1].

2 Evaluation of Speckles

In this contribution the evidence of speckle distribution is given by the answer of two questions:

1. Does the intensity distribution obey the negative exponential PDF?
2. Does the average speckle size follow the relationship of $\lambda z/2W$?

Both answers should be positive for the generation of fully developed speckle patterns and after its processing by numerical propagation [2].

The statistical behavior is analyzed by making up a histogram of intensity followed by the fitting of the curves by gamma as well as negative exponential PDF. The gamma PDF depends on 2 parameters of α and β , whereas the negative exponential PDF

is described by the parameter of μ . If $\alpha=1$ and $\beta=\mu$, i.e. $\beta/\mu=1$, the gamma PDF reduces to negative exponential function what is a typical property of speckles.

The autocorrelation function delivers the correlation length, the distance between lateral spatial locations where the intensity values are still correlated statistically with each other. This corresponds to the average speckle size of the observed distribution and is evaluated by measuring the distance between the central global maximum and the first local minimum. Meanwhile this average speckle size follows the relationship of $ASS=\lambda z/2W$ with λ as the wavelength, z the propagation distance and $2W$ the aperture width for squared, but $ASS=1,22\cdot\lambda z/2R$ for circular apertures having a radius of R . Both criteria, i.e. the negative exponential PDF and the ASS are used for speckle validation [1].

The propagation of optical wavefields is represented by the Kirchhoff diffraction integral. This can be simplified to a Fresnel transform for the paraxial regime which corresponds to a Fourier transform of a multiplication of the complex amplitude distribution $U(x',y')$ in object plane times a parabolic phase propagator. This is called direct method (DM). The Kirchhoff diffraction integral can be seen as a convolution of $U(x',y')$ by the impulse response of free space which is generally performed in spectral domain by multiplication of its Fourier transforms. Then the spectral result is transformed back to the spatial domain by inverse Fourier transform. If this impulse response is approximated parabolically we call this spectral method (SM). The distributions and the following propagation can be only represented numerically by sampling. This results in 2 consequences: I) replicas appear due to propagation at a lateral replica period $RP'=\lambda z/\delta X'$ with $\delta X'$ as pixel size at object plane, II) there is a different pixel size δX in the diffraction plane for each method. For DM the pixel size scales with the distance by $\delta X=\lambda z/(N\delta X')$ with N as an integer number of samples while for SM δX remains const., i.e. $\delta X=\delta X'$ [2]. This behavior concerns both lateral coordinates of x,y .

