Adaptive control of laser speckle fields in optical microscopy for high-resolution imaging

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Introduction

Spatial resolution (lateral as well as longitudinal) is a core issue in many fields of optical imaging: astronomy, microscopy, optical data storage, cell biology, ophtalmology, laser scanning, photolithography, atom trapping. The imaging resolution is related to the wave nature of light, hence limited by the point spread function (PSF) of the objective lens. I here present first results, which are several simulations based on the well-known Kirchhoff diffraction integral [2] and characterization measurements of the components for a model microscopic imaging system.

The PSF

The point spread function (PSF) describes the response of an imaging system to a point source or point object. The degree of spreading (blurring) of the point object is a measure for the quality of an imaging system. A perfect objective lens is limited by the diffraction limit, giving an airy disc as PSF (Figure 1).

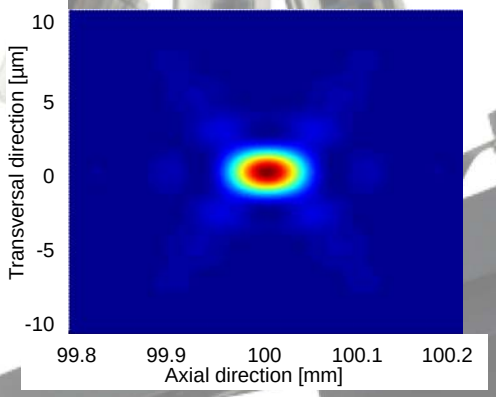

***Figure 1:** 3D point spread function (PSF) of an diffraction limeted lens*

The bigger the transversal spot, the more fuzzy the image will be. A simple lens becomes blurred very fast by moving out of focus (Figure 2).

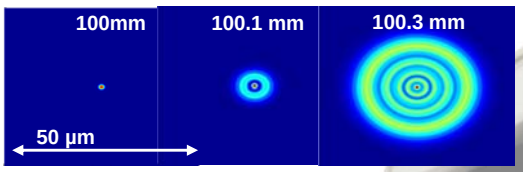

Figure 2: Very fast increase of transversal spot size by moving the image plane out of focus from 100mm to 100.1mm to 100.3mm.

Modifying the PSF

There exist several methods to modify the PSF:

- diffractive optical elements (DOE),
- refractive-diffractive hybrid elements,
- holographic elements and
- axicons.

They all perform phase and/or amplitide modulation, reshaping the imaging PSF for a desired application.

Figure 3 & 4 show an extended depth of field (DoF) with homogeneous spot size.

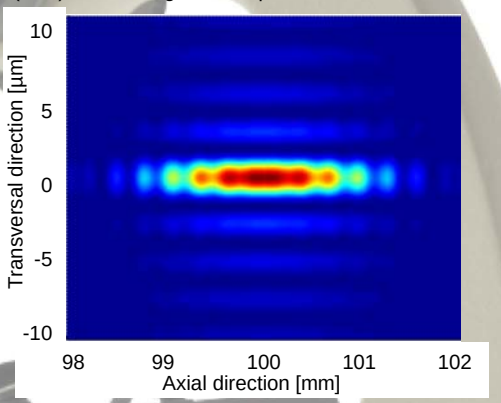

***Figure 3:** Modulated 3D point spread function (PSF) by a binary multi-zone complex pupil filter.*

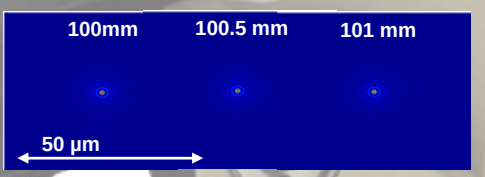

Figure 4: Homogeneous transversal spot size over the full depfth of field (DoF) from 100mm to 100.5mm to 101mm

It is also possible to generate a narrower PSF either in lateral as well as in axial direction, resulting in a higher resolution than the diffraction limit would allow (Figure 5).

Drawbacks:

- intensities can be drastically reduced,
- additional image distortion due to increased side lobes

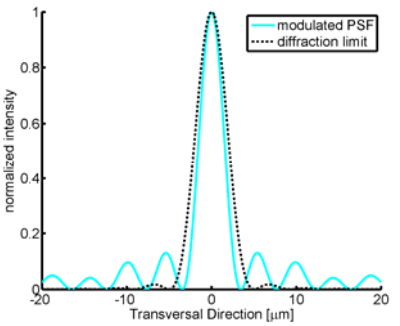

***Figure 5:** Modulated point spread function (PSF), showing a better resolution than the diffraction limit would allow*

Modifying the light

For practical purpose, a liquid crystal spatial light modulator (LC-SLM) will be used, which offers complete control over the wavefront. This allows for local adjustment of amplitude (between 0 and 1) or phase (between 0 and 2π) independently (Figure 6).

Phase-only pupil filters have taken the lead over amplitude filters due to better transmission and therefore higher conversion efficiency.

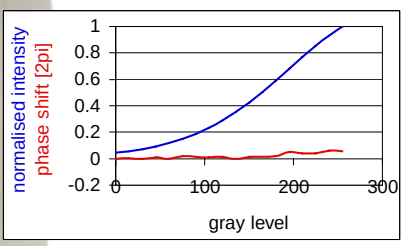

***Figure 5:** Light modulation by a spatial light modulator in amplitude alignment.*

Outlook

- Practical verification of the simulations.
- Implementation of the high-resolution pupil filters into a model microscope.
- Reduction of phase fluctuations due to scattering media (biological tissue, dirt, water, …) with an iterativ feedback loop modulating the phase shift.
- Focusing the light into a fluctuating phase medium or collection of light from an object that is hosted inside such a medium.

This might deliver a novel microscopy method capable of high-resolution, label-free real-time monitoring of living cells in vitro.

References
[1] Gundu, P.N., E. Hack, and P. Rastogi, *High efficient superresolution combination filter with twin LCD spatial light modulators,* Optics Express 13, **2005,** 2835-2842.
[2] Goodman, J.W., *Introduction to fourier optics*, McGraw-Hill, **1968**.
[3] Xu, Y., et al., *Ultra long high resolution beam by multi-zone rotationally symmetrical complex pupil filter*, Optics Express 15, **2007**, 6409-6413.

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