Technology Offer

Microscopy: Differentiable model-based adaptive optics with transmitted and reflected light
Ref.-No.: 2022-6511-FG

The invention relates to a method and illumination device for optimizing parameters of a physical light propagation model, in particular a light propagation model in a confocal laser microscope using a raster scanning method. The method can determine aberration corrections that go beyond a predetermined model of aberrations, such as combinations of Zernike modes.

Advantages
- Improves resolution and intensity of the image in an efficient way
- Needs a small number of measurements for finding aberration corrections
- Suitable for epi-detection configurations

Applications
- Laser scanning microscopy
- Biological imaging

Background
Machine learning offers novel approaches to correct for aberrations encountered when imaging through scattering materials with transmitted and reflected light. However, for training a neural network large datasets are required, because the parameters of the neural network need to be adjusted i) to work under a wide range of conditions and ii) to learn the underlying image generating process through the optical system. The training dataset can be reduced, if information about the image generation process is a priori known. However, training datasets are often based on combinations of Zernike polynomials and hence might not accurately capture all aspects of the aberrations. Additionally, for strongly scattering samples higher orders of Zernike modes are required, which further increases the training dataset. Therefore, for at least those optical systems for which a priori information of the image generation process is known, an improved method for determining/correcting the aberrations in the optical system is needed.

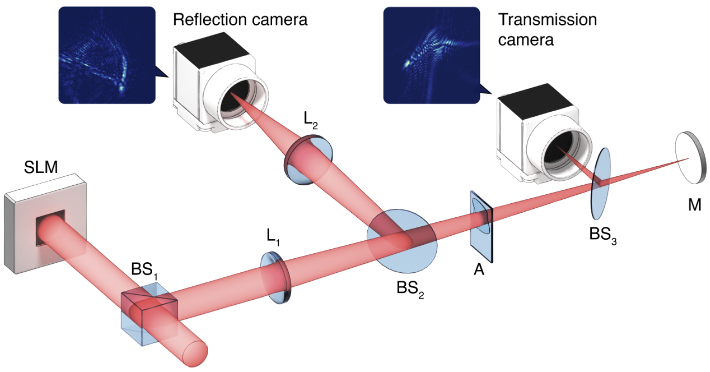

Fig. 1; experimental setup: light reflected off a spatial light modulator (SLM) passes through an aberration (A) and is focused onto a first (transmission) camera; for experiments in an epi-detection configuration, light reflected off the mirror M at the sample plane is additionally recorded with a second (reflection) camera; also shown is the imaged light distribution recorded by each camera; BS = beam splitter, L = lens.

Technology
The method uses a model of the optical system, which describes the light propagation through the optical system as a differentiable function. The model also includes unknown parameters, which account for aberrations occurring in the system and which are to be determined. For determining the unknown aberrations/parameters a number of output images resulting from corresponding input phase modulations are recorded and the unknown parameters are adjusted so that the input-output relationship of the computational model and the experimental setup match. Once the aberration pattern in the optical system is determined, the aberrations can be corrected by setting a complementary aberration pattern into the excitation path of the optical system; which can be done, for instance, by means of a spatial light modulator.

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de

Transmission-based control

Reflexion-based control

A microscope, employing the method according to the invention, is depicted in Fig. 1. In the microscope an expanded and collimated laser beam is reflected off a spatial light modulator (SLM) with a beam splitter cube BS1 and a part of the beam is imaged onto a transmission camera over a beam splitter BS3. For experiments with reflected light, the remaining part of the beam is additionally sent to a mirror at the sample plane (having the same focal plane as the transmission camera). The mirror serves as a proxy for a reflecting sample. Light reflected by the mirror is imaged onto a reflection camera with a beam splitter BS2. Aberrations are introduced between BS2 and BS3 by means of a scattering element A. The microscope can determine the aberration A by: a) providing a physical, mathematical differentiable model on a computer; b) irradiating an input light distribution I_0 by the collimated laser beam into the excitation path of the microscope; c) scattering the light I_0 with the scattering element A, thereby transforming I_0 to form the transmission light distribution I_{TR}; d) recording the light I_{TR} by means of the transmission camera; e) transferring the recorded light distribution I_{TR} to the model; and f) calculating transmission distortion parameters V_{TR} of the model based on the recorded distribution I_{TR}, wherein the parameters V_{TR} describe the aberrations introduced by the scattering element A in the excitation path.

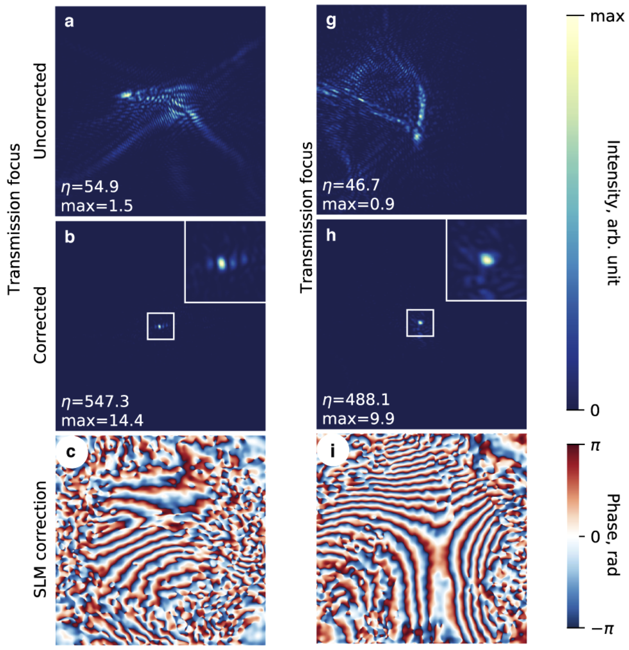

Fig. 2: a uncorrected first focus recorded in transmission (its distortion due to aberrations is evident); **b** corrected first focus recorded in transmission (focus is surrounded by a white frame and magnified in the insert); **c** wavefront correction at SLM obtained after a two-step transmission-based optimization and used for aberration correction of the first focus; **g** uncorrected second focus recorded in transmission (its distortions due to aberrations is evident); **h** corrected second focus recorded in transmission (insert shows a magnification of this focus); **i** wavefront correction at SLM recovered only from reflected light in a two-step optimization and used for aberration correction of the second focus; "max" indicates the maximum of the colorbar, η is the enhancement, and the field of view is 1766 µm by 1766 µm.

Also, the microscope can determine the aberration A by: performing the above-mentioned steps a) to c); reflecting the light distribution I_{TR} by the mirror M; scattering the reflected light I_{TR} with element A to generate the reflection light distribution I_{RE}; recording the distribution I_{RE} with the reflection camera; transferring the recorded I_{RE} to the model; and calculating reflection distortion parameters V_{RE} of the model based on I_{RE}. The microscope can correct the aberrations A by setting a distortion pattern V^*_{TR} or a pattern V^*_{RE} on the SLM, wherein V^*_{TR} and V^*_{RE} are based on the determined parameters V_{TR} and V_{RE}, respectively. Examples of such corrections are shown in Fig. 2.

Patent Information

DE 10 2020 119 566 A1
WO 2022/018002 A1

Publications

Ivan Vishniakou and Johannes D. Seelig, Differentiable model-based adaptive optics with transmitted and reflected light, Optics Express, Vol. 28, No. 18 / 31 August 2020 / 26436

Contact

Dr. Franz Gadelmeier
Patent- & License Manager
Physicist
Phone: +49 89 / 29 09 19-13
Email: gadelmeier@max-planck-innovation.de

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de