A universal framework for wavefront-sensorless microscope adaptive optics

Qi Hu, Martin Hailstone, Jacopo Antonello, Jingyu Wang, Matthew Wincott, Martin J. Booth
Department of Engineering Science
Parks Road, Oxford OX1 3PJ, UK
University of Oxford
E-mail: {qi.hu, martin.booth}@eng.ox.ac.uk

KEYWORDS: adaptive optics, microscopy, aberrations

Optical system misalignments can induce system aberrations which affect microscope imaging quality. When imaging deep in specimens, image quality also suffers as sample induced aberrations affect the point spread function. Adaptive optics (AO) are devices that can be used to correct aberrations. To avoid cumbersome optical designs and in the cases when point like beacons are not available or signals are too weak to allow the operations of wavefront sensors, AO can only be operated without a wavefront sensor. This is known as sensorless AO; it involves inferring AO correction from a sequence of aberrated images [1]. The range of sensorless AO schemes that exist have different physical implementations, but can all be fitted into a general mathematical framework that permits comparison between the schemes. The framework for sensorless AO schemes consists of three key components: the aberration representation models, the system quality metric, and the convergence algorithm. The aberration representation models are used for phase modulation and corrections. Different forms of aberration models have different characteristics which make them useful for different applications. The system quality metric is used as the feedback signal for the correction process which is closely related to the imaging process of the microscope. The convergence algorithm is used to effectively optimise the correction process and thus the system imaging quality. To fully understand how to adapt a sensorless AO method to be suitable for an imaging system, we did a systematic comparison of various sensorless AO schemes [2–5] through both simulations and experiments, with the help of the universal framework. We expect the general trends revealed will provide a guideline when selecting a more suitable sensorless AO method to correct different types of aberrations when imaging different samples using different microscopes. The work provides us a deeper understanding of all sensorless methods and also helps to develop new sensorless AO schemes. This will lead to efficient sensorless AO microscope methods requiring fewer specimen exposures, that can increase the imaging depth and imaging quality to make fine features more visible without the introduction of complex and expensive optical designs.

1. M. J. Booth and B. R. Patton, "Adaptive Optics for Fluorescence Microscopy," in *Fluorescence Microscopy: Super-Resolution and Other Novel Techniques*, A. Cornea and P. M. Conn, eds. (Academic Press, 2014), pp. 15–33.
2. J. Tang, R. N. Germain, and M. Cui, "Superpenetration optical microscopy by iterative multiphoton adaptive compensation technique," Proc. Natl. Acad. Sci. **109**, 8434–8439 (2012).
3. N. Ji, D. E. Milkie, and E. Betzig, "Adaptive optics via pupil segmentation for high-resolution imaging in biological tissues," Nat. Methods **7**, 141–147 (2009).
4. Q. Hu, J. Wang, J. Antonello, M. Hailstone, M. Wincott, R. Turcotte, D. Gala, and M. J. Booth, "A universal framework for microscope sensorless adaptive optics: Generalized aberration representations," APL Photonics **5**, 100801 (2020).
5. "Home | AO tutorials," https://aomicroscopy.org/.