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Constrained optimisation for fast wavefront sensorless adaptive optics in microscopy

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Abstract content
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Specimen-induced aberrations severely affect the image quality in fluorescence scanning microscopy. Therefore, adaptive optics is used to restore diffraction-limited imaging [1]. Since direct wavefront sensing has been shown to be challenging in fluorescence microscopy, wavefront sensorless adaptive optics techniques have been developed. Instead of attempting to measure the wavefront, a suitable image quality metric is used as a feedback signal for the aberration correction procedure. This is a sequential process that consists of probing different settings of a wavefront correction element (e.g. a deformable mirror) until the corresponding value of the image quality metric is optimised.

Sensorless adaptive optics has been theoretically studied and experimentally demonstrated for different microscopy approaches [2]. In particular it was shown that a model of the image quality metric allows to reduce the time necessary for the aberration correction procedure. This minimises both the overall image acquisition time and undesirable side effects such as photobleaching and phototoxicity.

Here we consider the case when a quadratic polynomial is used to model the image quality metric [3]. This class of models has been widely employed in different microscopy approaches. We show that a robust aberration correction is achieved by solving a suitable constrained optimisation problem. We also show that, exploiting an a priori assumption about the unknown wavefront aberration, an incremental correction can be applied before the minimum number of measurements necessary to uniquely determine the aberration is reached. Our proposed algorithms are compared with other solutions present in the literature and validated in a laboratory environment.

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Primary author: Mr ANTONELLO, Jacopo (DCSC, Delft University of Technology)

Co-authors: Prof. KELLER, Christoph (Leiden Observatory, Leiden University); Prof. GERRITSEN, Hans (Molecular Biophysics, Utrecht University); Prof. VERHAEGEN, Michel (DCSC, Delft University of Technology); Mr VAN WERKHOVEN, Tim (Molecular Biophysics, Utrecht University)

Presenter: Mr ANTONELLO, Jacopo (DCSC, Delft University of Technology)

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