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Application of adaptive lens in sensorless AO-OCT for *in vivo* mouse retinal imaging

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INTRODUCTION

Sensorless optimization may play an important role in the future development of adaptive optics based imaging instruments due to reduced hardware complexity. In most cases, the search of correcting device shape is carried out by the use of an optimization strategy, which maximizes the value of a merit function which can be either the intensity in the focal spot for the laser optimization case or an image sharpening function in the case of the optimization of image quality. More recently an optimization method based on the cancellation of one aberration at a time was demonstrated. This strategy presents many advantages such as the use of fewer iterations and the absence of local maxima [1].

We demonstrated recently that the modal sensorless correction can be used in vitro in optical coherence tomography (OCT) with the use of a recently developed resistive deformable mirror [2]. Here we present extension of this system by application of novel Adaptive Lens (AL) for in-vivo imaging of mouse retinas. To achieve that GPU accelerated processing of the OCT data has been used allowing real time extraction of averaged intensity for arbitrarily selected retinal depth.

MATERIALS AND METHODS

In the experiment the wavefront was corrected using an Adaptive Lens (AL). The AL can generate low order aberrations: defocus (+/-6um PtV), astigmatism (+/-12um PtV), coma (+/- 5um PtV) and spherical aberration (+/- 0.5umPtV) through the use of 16 electrodes. The lens clear aperture is 11mm, and the lens in its rest position does not add optical power to the system. For this reason the lens has been mounted in front of to the focusing lens as illustrated in Fig.1 In order to correct those aberrations the lens was preliminary calibrated to determine the commands to the electrodes to generate the low order aberrations and their combinations.

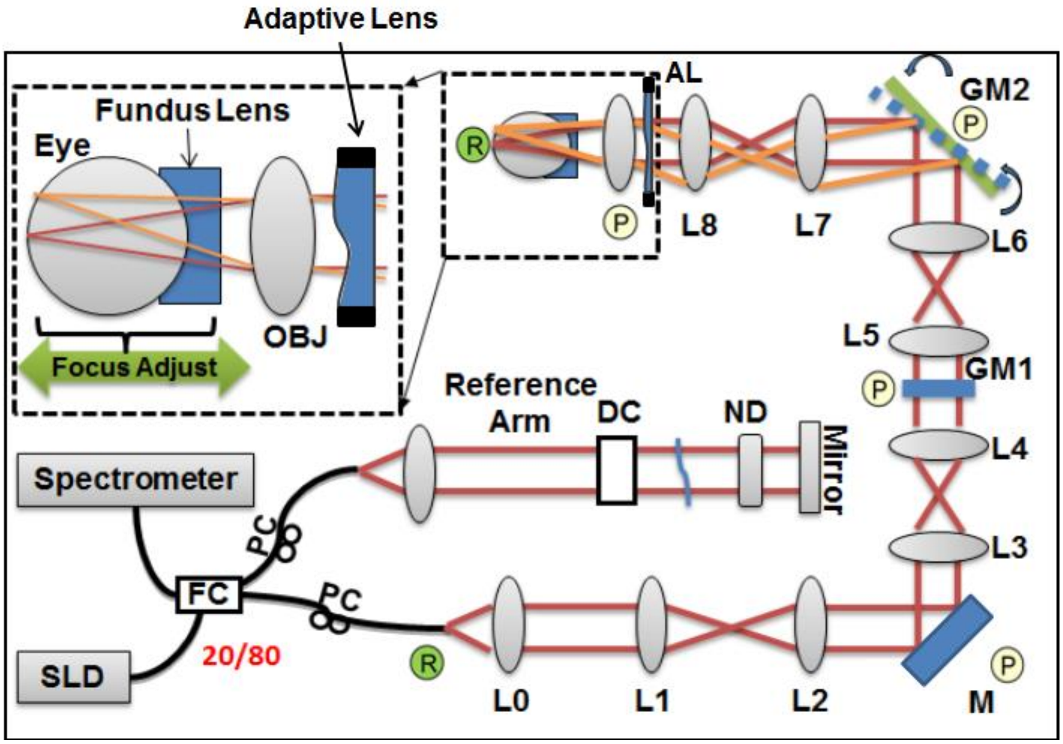

Fig. 1. Schematic of Adaptive lens based sensorless Adaptive Optics - Optical Coherence Tomography system. Note that there is no wavefront sensor in this system. Averaged intensity for arbitrarily selected retinal depth is used to search for AL deformations that correct aberrations in the mouse retina

The imaging AO-OCT system used to acquire data presented in this manuscript has been developed in collaboration with the BORG laboratory. Some details on OCT system components can be found in our previous publications [3]. Therefore we will only describe its main specifications. Briefly, the light source for OCT in the current configuration is a superluminescent diode (SLD) Broadlighter operating at 836 nm with 112 nm spectral bandwidth (Superlum LTD), allowing 3.5 µm axial resolution. A beam diameter at the last imaging objective was 11 mm allowing for up to 2 µm lateral resolution when a 25 mm focal length imaging objective was used. AO correction is optimized using intensity of the AO-OCT en-face projection views during volumetric data acquisition. In the current system configuration we used 11 mm diameter of the Adaptive Mirror. Light reflected from the sample is combined with the light from the reference mirror, and then sent to a spectrometer where the CMOS line detector Basler Sprint (spL4096-140km), was used at 50 kHz line rate at 2048 pixels and 10x20µm pixels (vertical binning), acquires the OCT spectrum. B-scan imaging frame rates (frames/s) are 200 fps, for 200 A-scans and 40 fps for 1000 A-scans. For the sensorless optimization process we used the OCT volumes consisting of 200 B-scans each with 200 A-scans allowing real time 1Hz update of merit function value.

RESULTS

To test the performance of our sensorless adaptive optics - optical coherence tomography system we evaluated the image quality of the Air Force Test target after correcting for residual aberrations of the refractive optics of AO-OCT sample arm. Figure 2 show an example of the results of this task. We were able to achieve improved resolution by using as the merit function the averaged square intensity [4] of the OCT en face projection images extracted from specific depth. As expected, the algorithm performed the optimization adjusting mostly the defocus and the astigmatism.

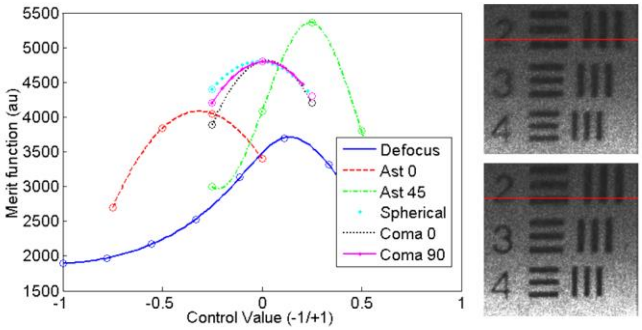

Fig. 2. Left: Graph of Merit Function of AO-OCT images for different values of aberrations generated by Adaptive Lens. Note that higher values correspond to better AO-correction. Right: En-face projection views of the AO-OCT images of the test target before correction (top) and after correction (bottom).

Next we tested performance of our sensorless AO-OCT system for in vivo imaging of mouse retina. Figure 3. shows an example result of this task. We were able to achieve improved resolution using the same procedure as described above. Note that in this case algorithm also fund merit function improvement for non zero values of both comas.

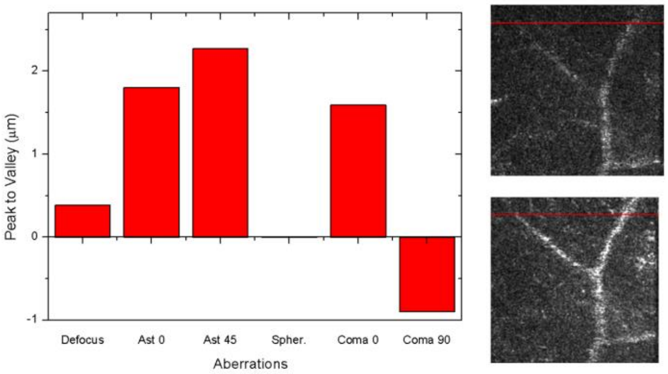

Fig. 3. Left: Results of Zernike aberration values found to maximize merit fiction during in vivo retinal imaging. Right: En-face projection views of the AO-OCT images of the mouse retinal vasculature before correction (top) and after correction (bottom).

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