High resolution flood illumination retinal imaging system with adaptive optics

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Purpose

The aim of the project is to design and build a high-resolution adaptive optics (AO) flood illumination retinal imaging system, capable of resolving single cones on the retina, compact, and cost efficient as compared to commercially available systems. The idea is to prove in principle that a commercial AO fundus camera can be built for a price range affordable to optometrists, and not only to hospitals or research laboratories, which increases the probability of early detection of certain progressive retinal pathologies in the general public. Our target is to image 4° of field on the retina, resolving single cones.

Methods

The focus of this study is to minimise the cost of high resolution imaging, with minimal compromise on the end result. The following paragraphs discuss the methods followed to design and optimise the retinal imaging system. They also report image quality metrics, in theory, of the proposed system.

The basic design of the optical setup is shown in fig. 1. The system consists of two main arms; AO arm, and imaging arm. The AO arm uses an infrared LED (OSRAM SFH4550, λ = 850 nm) as a light source, substituting a laser or an SLD, and eliminating the need for a despeckling element since the LED light is incoherent. The spot formed on the retina acts as a point source, sending light through the Badal (to correct defocus), reflecting from the deformable mirror (BMC DM, Boston Micromachines Corporation, 140 actuators, 5.5 µm of stroke), and onto a Shack-Hartmann wavefront sensor (Thorlabs WFS150-5C). The measured wavefront is used in a closed-loop to control the BMC DM.

The imaging arm starts with a high luminance green LED (Luxeon Rebel Tri-Star LXML-PM01-0100, λ = 530 nm) passing through the outer ring of the eye's pupil to illuminate the retina. The reflected light passes through the common path, is corrected on the BMC DM, and is collected on a scientific camera (QImaging Retiga 2000R). The field-of-view to be imaged on the retina is 4°. A wide field (20°) lower resolution imaging arm has been suggested as an extension for the system.

The choice of the BMC DM was based on its high number of actuators, adequate stroke, very low hysteresis, and the relatively lower price with a potential for further reduction in case of mass production. The DM performance was characterised using a Fisba Twyman-Green interferometer, and the RMS of the residual wavefront error after correcting a hundred randomly generated healthy eyes (Thibos' model) was considered.

The system was optimised using Zemax for best performance. The common path was optimised for the wavefront sensing wavelength. As a result of longitudinal chromatic aberrations, the imaging arm would suffer from a focal shift, which was compensated for with the positioning of the imaging lens (L8).

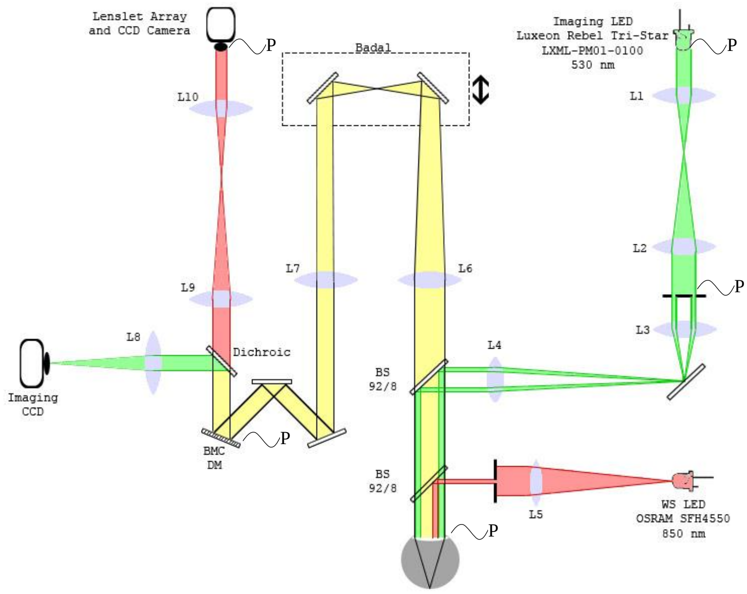

Fig. 1: Schematics of the retinal imaging system with adaptive optics. BS: beamsplitter. BMC DM: Boston Micromachines Corporation Deformable Mirror. P: pupil conjugate plane.

Results

The performance of the BMC DM was studied. Phase maps of a hundred healthy eyes were generated using Thibos' model. Assuming that defocus is corrected separately (using the Badal), the residual RMS wavefront error after correction using the BMC DM was found to be 0.093 waves, corresponding to a Strehl ratio of 0.76. The simulation was performed using IDL.

The optical design performance was quantified using Zemax. It achieves diffraction-limited performance in both arms. We report a residual RMS wavefront error of 3×10^{-4} waves at the Shack-Hartmann lenslet array level (fig. 2-left). We also report diffraction-limited spots for the whole 4° field at the retinal camera (fig. 2-right).

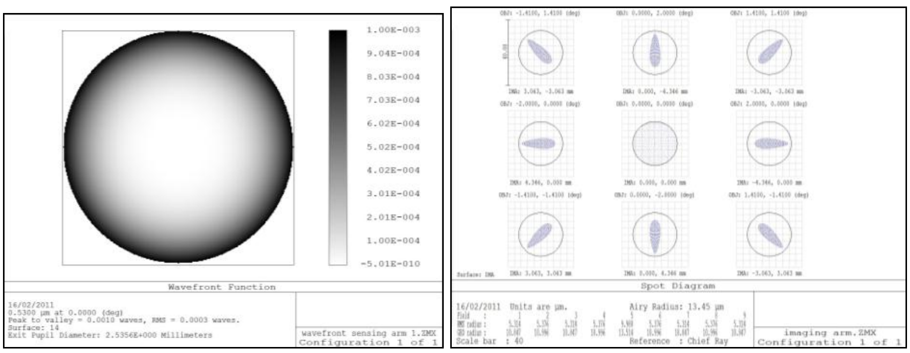

Fig. 2. Zemax residual RMS wavefront error of the AO arm at the Shack-Hartmann lenslet array level (left), and a spot diagram covering a 4° field at the retinal camera level (right).

Conclusions

A low-cost fundus camera with AO has been designed and simulated showing very little compromise on image quality. The device is currently being built. The next step will be to finalise the system and report image quality metrics in practice.

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