A pyramid wavefront sensor for ophthalmic applications

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1. Introduction
The pyramid wavefront sensor (PWS) was initially proposed by astronomers to measure aberrations introduced by the atmosphere [1]. It has since been used to measure the aberrations of the human eye [2], and within an adaptive optics (AO) loop to correct ocular aberrations [3]. Light from the pupil of interest (telescope or eye) is focused at the tip of a glass pyramid which splits the light into four parts. Each beam is re-imaged at a CCD to form four conjugate images of the pupil. A simple calculation using the intensity at equivalent pixels in each pupil image gives an estimate of the x and y wavefront gradients in the pupil. This information can be used to reconstruct the wavefront in the pupil, or as a feedback signal for a wavefront correcting device.

2. Experiment
Our system is designed to measure the wavefront aberrations in a human eye over a 6mm pupil at 675 nm. The re-imaged ocular pupil contains 12, 24, 48 or 96 samples across the pupil depending on the CCD binning. The system also incorporates a deformable mirror (DM), which can be used to correct aberrations or insert known ones when characterising the wavefront sensor. The coarsest spatial sampling option is matched to the minimum required to perform adaptive optics with this DM.

3. Interface
A custom LabVIEW interface controls the experiment. It sets basic experimental parameters and also performs pupil identification and ordering to allow for gradient calculation. The system can operate in open- (OL) and closed-loop (CL) mode. OL operation includes manual control of the DM and automatic acquisition of the influence function matrix (IFM) – response of the system to DM pokes. One feature of CL operation is that the loop gain can be fixed or variable depending on the value of a metric – we use the wavefront residual root-mean-square (rms) after correction. This requires live wavefront reconstruction. The individual Zernike terms are displayed to allow, for example, optimization of the Bland setting.

4. Calibration
The system was calibrated in two stages. Initially, PWS measurements of aberrations introduced by the DM were compared to commercial interferometer (Fisba) of artificial phase plates with the influence function of the DM. This simulation predicts the mirror commands required to fit the phase and the residual after fitting in each case. Correcting the aberrations experimentally gives very similar results to the simulation.

5. Results
Ocular aberrations were recorded without AO correction (OL mode) for a number of subjects, typically for 15s at a rate of ~80 Hz. It is important that the PWS operates within its linear range so that the aberrations do not saturate the sensor and are measured accurately. The appropriate modulation is found for each subject by trial and error. The power spectrum of the rms shows frequency content out to 40 Hz and lies well above an identical analysis of an artificial eye.

6. Conclusions
Based on the results obtained so far we conclude that the PWS performs very well in OL, limited here mainly by available DM stroke but that care should be taken in OL to stay within the linear range of the sensor. We are incorporating a psf camera into the science arm to allow for further verification of the CL performance.

References

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