Compact Adaptive Optics

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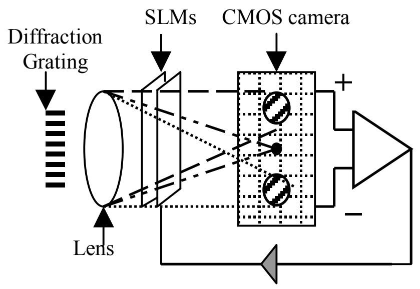
Summary

For control of an adaptive optical system it is not strictly necessary, and may even be detrimental, to reconstruct the input wavefront. A sufficient condition for satisfactory operation of an adaptive optical system is the ability to drive a wavefront modulator using a null sensor, where a control signal derived from a wavefront sensor system indicates the size, location and (preferably) the direction of the wavefront error. Thus, if the wavefront modulator is providing full correction of the input wavefront error, the control signal will be zero and the wavefront modulator will not be driven from its present position.

Phase-diversity is an algorithm for reconstruction of wavefront phase from data corresponding to images of the input wavefront intensity on two planes normal to the direction of propagation and located at different positions along the axis of propagation. These planes are generally described as symmetrically-placed about the image plane, but can equally-well be symmetrically-placed about the system input pupil, in which case the phase diversity algorithm becomes essentially the same as the wavefront curvature algorithm. If the input wavefront is plane, the intensity on the two measurement planes will be identical and the difference between the images will be zero, satisfying the requirements for a null sensor. If the input wavefront is distorted the propagation between the measurement planes results in convergence (concave wavefront) or divergence (convex wavefront) and the resulting intensity difference between the measurement planes is indicative of the location, magnitude and direction of the wavefront curvature.

The data on the two image planes is recorded using various approaches, including physical displacement of the image plane, use of a vibrating spherically-distorted mirror, beam splitters and folded optical paths, or by the use of off-axis Fresnel lenses. Each of these approaches has its merits and drawbacks, but each corresponds to the recovery of phase information from two data sets recorded under different focus conditions.

At the expense of assumptions imposed on the uniformity of the input illumination, the current work on two-defocus methods has progressed a long way from those used in electron microscopy in the 1970's and present techniques have demonstrated real-time data reduction with high (sub-nanometre) accuracy. However, in all cases the two data sets are recorded under conditions where the wavefront is subject to a known defocus aberration between the two measurements. Some obvious questions that this poses are: 'What, if anything, is unique about the defocus aberration used? Can equally satisfactory, or better, results be obtained using other aberration functions? If so, what generic properties should suitable aberration functions possess? Are the restrictions on the uniformity of the input wavefront necessary? Are there optimum aberration functions and does optimisation depend on *a priori* knowledge about the nature of the input wavefronts? Do the optimum aberration functions depend upon whether the objective is a null sensor for use in an adaptive optics or a wavefront sensor for use in metrology or other applications?'



This figure shows a compact adaptive optics system based on the use of a diffractive optical element to produce simultaneously a corrected image and the phase diversity wavefront sensing data. Use of a CMOS camera permits extended integration on the central science image whilst collecting wavefront sensing data in the diffractive orders. To achieve a compact design the use of transparent wavefront modulators, such as liquid crystals, has been assumed. By positioning the wavefront modulators at appropriate locations anisoplanatic effect can be compensated. Use of a diffractive optic element is not the only way to combine phase diverse wavefront sensing and a corrected image on the same focal plane.

In this presentation we will explore the generalisation of the phase diversity approach, and show what properties the aberration function used should have in order to provide a null sensor. We will show that this general approach offers scope for the implementation of adaptive optics systems that can be remarkably compact and in which the corrected image can be stored simultaneously with an estimate of residual wavefront errors averaged over the exposure time. We will consider the issues of data reduction using this generalised approach to reconstruct the input wavefront shape.