Low cost adaptive optics

Optica adaptativa de bajo coste

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ABSTRACT

In this work I present a description of low cost components for adaptive optics and future prospects in the field.

Key words: Adaptive Optics, Wavefront Sensors, Deformable Mirrors.

REFERENCIAS Y ENLACES


1. Introduction

Adaptive optics (AO) was first suggested by Babcock [1] in 1953 as a means of overcoming the deleterious effects of atmospheric turbulence in optical ground-based astronomical imaging. Because of technological limitations, adaptive optics was not implemented on large telescopes until the late eighties [2] and nowadays all of the World’s large telescopes are equipped with AO systems. These are highly sophisticated and complex “one-off” instruments that typically cost on the order of $10-15M.

Although AO systems can be rather complex, the basic principle is quite simple, as shown in Fig. 1 in the context of astronomical imaging. In essence, the distortion (in astronomy this is due to atmospheric turbulence) is compensated by the action of a deformable mirror (DM) or other spatial light modulator. The signal that controls the deformable mirror is usually derived from a wavefront sensor (as shown in the Figure), and the whole system works in closed loop.

Although we normally think of an AO system as complex and having many degrees of freedom (e.g. a large number of actuators on the DM), it should be noted that the ubiquitous CD or DVD player is a low cost (~ a few dollars) AO system with feedback on focus and tracking (“tip-tilt”). The question then arises: can high order AO systems be constructed at low cost, and what are the critical technologies for the components and system design?
2. Components for adaptive optics

2.a. Wavefront sensors

The classic wavefront sensor for adaptive optics is the Shack-Hartmann sensor, shown schematically in Fig. 2. A CCD or CMOS camera is placed at the focal point of a lenslet array, and the average wavefront slope over each lenslet recorded from the displacement of the focused spot from a reference position. The wavefront can be reconstructed from the average slopes, or more usually the x- and y-displacements are fed directly into the control system.

The Shack-Hartmann sensor has the virtue of simplicity but is by no means the only way of measuring a wavefront or of providing wavefront information as part of a closed-loop adaptive optics system. Other possible sensors include:

- Common-path interferometry
- Shearing interferometry
- Pyramid wavefront sensor
- Curvature Sensor
- Modal wavefront sensor
- Phase-diversity wavefront sensor

In addition to the hardware, there are many possibilities for processing signals, depending upon the task (e.g. wavefront reconstruction or closed loop AO).

2.b. Deformable mirrors

Historically, the lack of availability of deformable mirrors has severely limited the implementation of adaptive optics, due to their high cost, bulk and general inconvenience (e.g. large power supplies). The classic push-pull piezo or PMN zonal device, typified by mirrors from Xinetics Corporation, has the potential for excellent correction but, at $1-3K per actuator including power supplies, is too expensive for most applications. One less expensive approach is to use bimorph mirrors, shown schematically in Fig. 3, which are particularly effective for atmospheric turbulence as their modal structure is well-matched to that of turbulence.

Other possible technologies include:

- Membrane mirrors. These are potentially very low devices but suffer from limited stroke and are rather fragile.
- MEMS segmented devices.
- MEMS continuous devices.
- Magnetically actuated devices.
When comparing deformable mirrors for an application, it is essential to take a task-based approach [3] to the comparison, for example, as carried out for applications in the eye by Dalimier and Dainty [4].

2.c. Control system

In the simplest approach to AO control, temporal and spatial control are decoupled, with the temporal aspects typically based on a simple integrator and the spatial aspects implemented with a least-squares controller. Such controllers are adequate for many tasks but are not optimum as they do not use prior knowledge of the spatio-temporal statistics of the aberration to be corrected or of the system noise. One approach to control in AO is based on Kalman filtering and prediction.

A key feature of the system design and control is the matching of the wavefront sensor modes to those of the mirror: the sensor must be able to detect all modes that the mirror can produce, as well as all modes of the aberration up to a level that determines the residual error.

As regards hardware, the control for most adaptive optics systems typically resides on a PC or a special DSP-based controller. However, for low cost systems, a better solution might be to implement the control on an FPGA.

3. Applications

Apart from astronomy, the main current applications of adaptive optics are:

- Retinal imaging
- Vision enhancement
- Lasers
- Confocal microscopes
- Free space optical communications

These and future applications depend strongly on technological developments at the component level and on cost-savings of large-scale manufacture.

4. Future prospects

Commercial adaptive optics systems for imaging in the eye and for demonstrating the visual benefit of aberration correction will shortly be available for $50K to $100K. As the cost of components falls, the cost of complete systems should fall correspondingly. However, a disruptive application, such as the incorporation of AO into a consumer product, could lead to AO systems costing a few dollars.

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