Adaptive Optics Demonstrator for Education and Basic Research

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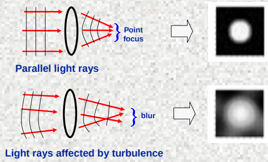
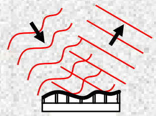
Abstract: We have constructed an enclosed, standalone adaptive optics system (the AO Demonstrator) that uses a deformable mirror to correct a distorted input beam. It is designed and built primarily for educational purposes, but can suffice as a simple research tool for testing deformable mirror control algorithms. It has a simple red laser to serve as the test light, a 37-actuator Intellite deformable mirror for correcting aberrations, a Shack-Hartmann wavefront sensor for sensing the aberration in the light, a control computer, several high-voltage drivers, and a TV for viewing the focused laser point in real time. The system has a modular C++ graphical user interface to simplify operation. The complexity of interaction with the system ranges from simple concept exhibition to high-order source code modification.

What is Adaptive Optics (AO)?

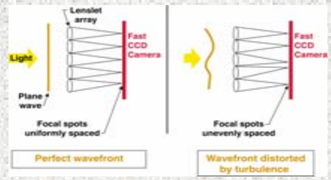
In many signal-processing applications, the natural, linear propagation of light is hindered by an intervening fluid. This occurs in astronomy (the turbulence of the atmosphere), laser communications (air turbulence), and retinal imaging (vitreous and aqueous humor). If light is bent by the varying indices of refraction in the fluid, it becomes difficult to focus. This blurring effectively reduces the amount of information in the light.



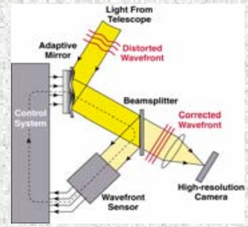


Adaptive Optics is the science of mechanically correcting this distortion with special flexible optics called "deformable mirrors." The diagram above shows a deformable mirror perfectly correcting a distorted wavefront, shown as a twisted line. Because the distorting fluid typically moves very quickly, the deformable mirror must change position rapidly to keep up (at 1 kHz for astronomy). A common type of deformable mirror is a micromachined membrane (MEMS). In this design, a thin membrane is stretched taut over a grid of metal actuators, which can be charged up to certain voltages to attract the membrane and change the shape of the mirror. A computer is used to calculate the control voltages that are sent to the deformable mirror.

But the computer must be able to sense the shape of the wavefront before attempting to correct it with a deformable mirror. This can be done in many ways, one of which is shown below (a Shack-Hartmann wavefront sensor). In this type, an array of small lenses is inserted into the beam. The beam from each lens forms a focused spot whose position is proportional to the tilt of the wavefront in that lens. A CCD camera can be placed at the focal plane to sense the positions of each of the spots; the entire grid of spot positions can be used to reconstruct the wavefront shape. Only part of the light is sent to the sensor; the rest is sent through normal analysis optics.



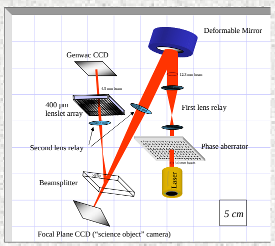
A typical adaptive optics system will look something like this, an example from astronomy. A large telescope gathers light and sends it to the AO system to be corrected. In "closed loop" operation, the control computer is constantly updating the position of the deformable mirror based on new information from the wavefront sensor. The AO Demonstrator is designed in this way, with a Shack-Hartmann wavefront sensor and a membrane micromachined (MEMS) mirror.

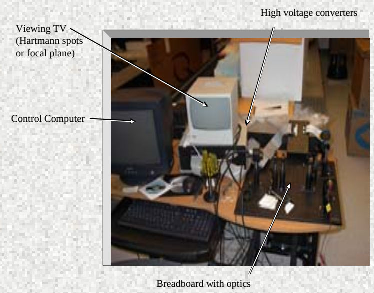


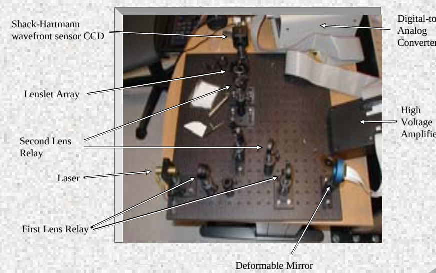
System Design

The AO Demonstrator is designed to be compact (~40 cm) and easily transportable, with no components hidden from view:

1. The 1 mW 632 nm laser provides source light for a guide star (wavefront sensing alone) and/or a point source science object.
2. The "phase aberrator" can be a phase plate, a hot plate, a piece of glass, etc., or anything that disturbs the image sufficiently.
3. The lens relays, which are just pairs of lens of different focal lengths, resize the beams. The first lens relay is analogous to the astronomical primary and secondary mirrors.
4. The deformable mirror is provided by Intellite. It is a 37-actuator continuous facesheet MEMS Al-coated device with a 6 µm maximum deflection.
5. The AoA lenslet array in the Shack-Hartmann wavefront sensor has square lenslets (400 µm wide) with 71 mm focal lengths.
6. The Genwac CCD camera, for the Shack-Hartmann wavefront sensor, images the spots produced by the lenslet array.
7. The viewing TVs allow the Shack-Hartmann spots and the science object in the focal plane to be viewed simultaneously.



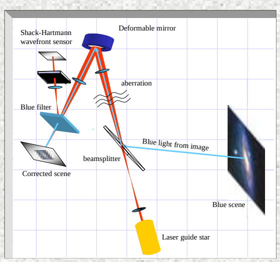




Demo Brainstorming

The AO Demonstrator was designed to have three levels of interaction:

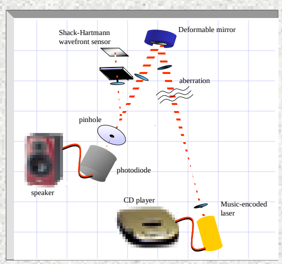
1. *Simple*. A facilitator has several demo graphical user interfaces (GUIs) in hand, which are useful for simple ~10 min demonstrations that communicate the general principles of adaptive optics. Two ideas for simple demos are illustrated to the right; one of the GUIs is also shown.
2. *Complex*. Users can run different methods of correction and observe results in terms of quickness, quality of correction, error, etc. This requires a greater familiarity with (a) the optical layout, (b) standard reconstruction methods, and (c) wavefront sensing methods. This would be meant for students or incoming CfAO members who would like to understand the engineering of AO.
3. *Complete*. The C++ source code is written to be modular and easily changed. Users can write new centroiding (spot positioning in the Shack-Hartmann sensor) methods, reconstruction routines, and merit-figuring components, possibly to permanently add functionality to the entire system. Users can also change the optical layout of the system. This type of interaction would be ideal for class projects or CfAO researchers (to test out ideas on a simple platform).



Demo #1: Imaging a scene with a laser guide star

Demo #1: Use a blue scene (several meters away) as the science object. Use the red laser as a guide star that (a) samples the same aberration as the scene and (b) is visible only to the Shack Hartmann wavefront sensor (wavefront sensors perform better with point sources). With a blue filter in front of the science camera, only the light from the scene is focused and used for science. In the wavefront sensor, the laser is bright enough the overpower the scene, which is desired.

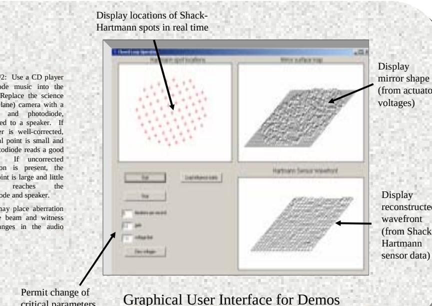
Users can place aberration (glass, plates, hair dryers, etc.) into the beam and observe the scene as it sharpens.



Demo #2: Encoded music

Demo #2: Use a CD player to encode music into the laser. Replace the science (focal plane) camera with a pinhole and photodiode, connected to a speaker. If the laser is well-corrected, the focal point is small and the photodiode reads a good signal. If uncorrected aberration is present, the focal point is large and little signal reaches the photodiode and speaker.

Users may place aberration into the beam and witness the changes in the audio noise.



Graphical User Interface for Demos