MODULAR ADAPTIVE OPTICS TESTBED FOR THE NPOI

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ABSTRACT

The Naval Prototype Optical Interferometer (NPOI) is a long-baseline, multi-station interferometer whose collection apertures can be relocated to provide flexible baseline lengths. While NPOI has the longest baseline at optical wavelengths in the world, the sensitivity of the interferometer is limited by the size of the individual collection apertures which are currently 0.5 meters in diameter. NPOI is currently upgrading its collection apertures to 1.4 meter diameter light weight telescopes to increase the sensitivity. At its location on the Anderson Mesa in Arizona, the chosen diameter of the telescope apertures is much larger than the average r_0 of the site. As a result, adaptive optics must be used to correct for the wavefront aberrations.

Several adaptive optics system configurations are suitable to provide the required wavefront correction, but it is highly desirable to have the adaptive optics systems as a component of the telescopes. This is being accomplished by designing the telescopes so that the adaptive optics system resides in the base of each telescope allowing a truly reconfigurable array. Thus evaluating and characterizing the performance of the adaptive optics systems is a critical component of identifying the desired adaptive optics system to support the move to larger aperture telescopes.

This paper outlines a modular, electro-optical testbed that has been constructed for characterizing candidate adaptive optics systems for use at NPOI. The testbed makes use of innovative technologies to characterize the spatial and temporal performance of an adaptive optics system. Spatial performance is evaluated using a spatial light modulator liquid crystal device while temporal response is evaluated with a fast steering mirror that is used in series with the liquid crystal device. We report on the capabilities of the testbed and on the initial characterization of a low cost portable adaptive optics system.

1. INTRODUCTION

Atmospheric aberrations degrade the performance of large aperture astronomical telescopes effectively reducing their resolution below that of a much smaller telescope. The atmospheric characteristic diameter, r_0, describes the effective diameter the atmosphere reduces larger aperture telescopes to, generally in the order of 10 to 20 cm for visible light[1]. To utilize larger aperture telescopes, adaptive optics (AO) systems are often employed. These closed loop systems measure wavefront aberrations and apply the phase inverse on an active optical element to remove the aberrations in the end result (see figure 1). These systems require high speed operation and large enough dynamic range to account for the large magnification from atmospheric aberrations through the large aperture ground telescopes.

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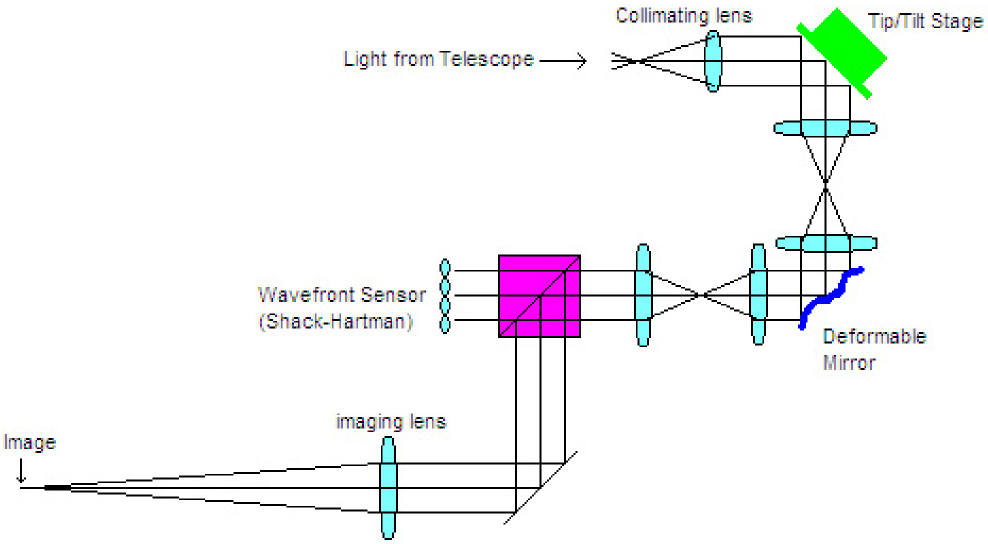


Figure 1. The entrance pupil of the telescope in a standard AO system is reimaged on the tip/tilt stage and deformable mirror for removing aberrations and then imaged on the wavefront sensor and imaging camera.

The Naval Research Laboratory (NRL) operates a reconfigurable large baseline optical interferometer called the Naval Prototype Optical Interferometer (NPOI) located in Flagstaff, Arizona. The array is being populated with 1.4 meter telescopes which require adaptive optics systems to operate in the visible (below 0.8 µm) at this site. The array is reconfigurable (see figure 2) with baselines ranging from 8 to 465 meters also requiring lightweight and portable telescopes and adaptive optics systems. To this end, NRL has developed 1.4 meter carbon fiber reinforced polymer lightweight telescopes with Composite Mirror Applications, Inc[2]. These telescopes will weigh roughly 350 pounds for the entire optical telescope assembly and all optics[3]. NRL has also been developing small portable AO systems and testing them on large aperture telescopes[4,5].

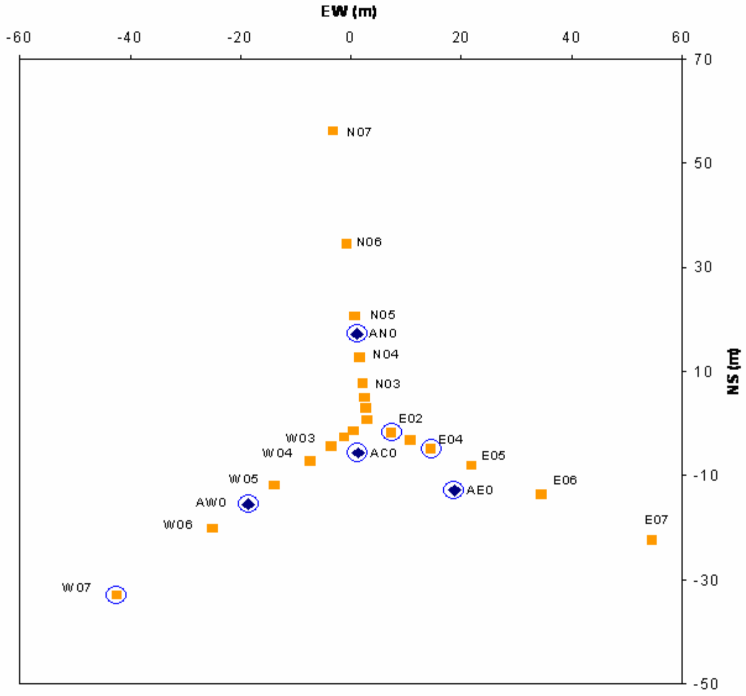


Figure 2. A diagram of the inner portion of the NPOI array. Squares represent existing pads where telescopes could be mounted, and the circles represent existing apertures mounted on those pads.

Most AO systems are tested rigorously in the laboratory based on design parameters for the specific site and tuned before they are installed on the telescope specific application. The design philosophy for the NRL AO systems supports reconfiguration and the portability to be used on different telescopes during the course of a day. The new 1.4 meter lightweight NPOI telescopes will have the adaptive optics systems permanently mounted on the telescopes and the telescopes moved between stations. This provides the opportunity for the AO systems be developed with an emphasis on performance rather than reconfigurability. This paper describes the development of a testbed for measuring the performance of the NRL portable AO systems

2. ADAPTIVE OPTICS TESTBED RESULTS

The NRL portable adaptive optics system is constructed similar to the standard model shown in figure 1. However, as seen in figure 3, the tip/tilt mirror is currently not implemented in this version. The purpose of this testbed is to characterize the deformable mirror and custom reconstruction algorithm. The system employs a HeNe laser expanded and collimated to a 15mm diameter beam reflected off the 37 element OKO Technologies Micro-Electro-Mechanical (MEM) continuous facesheet thin membrane deformable mirror. The light is then split, with half of the light sent through a 20 x 20 element Shack-Hartmann wavefront sensor and imaged onto a 128 x 128 pixel Dalsa fast readout camera. The other half of the light is sent to a USB CMOS imaging camera.

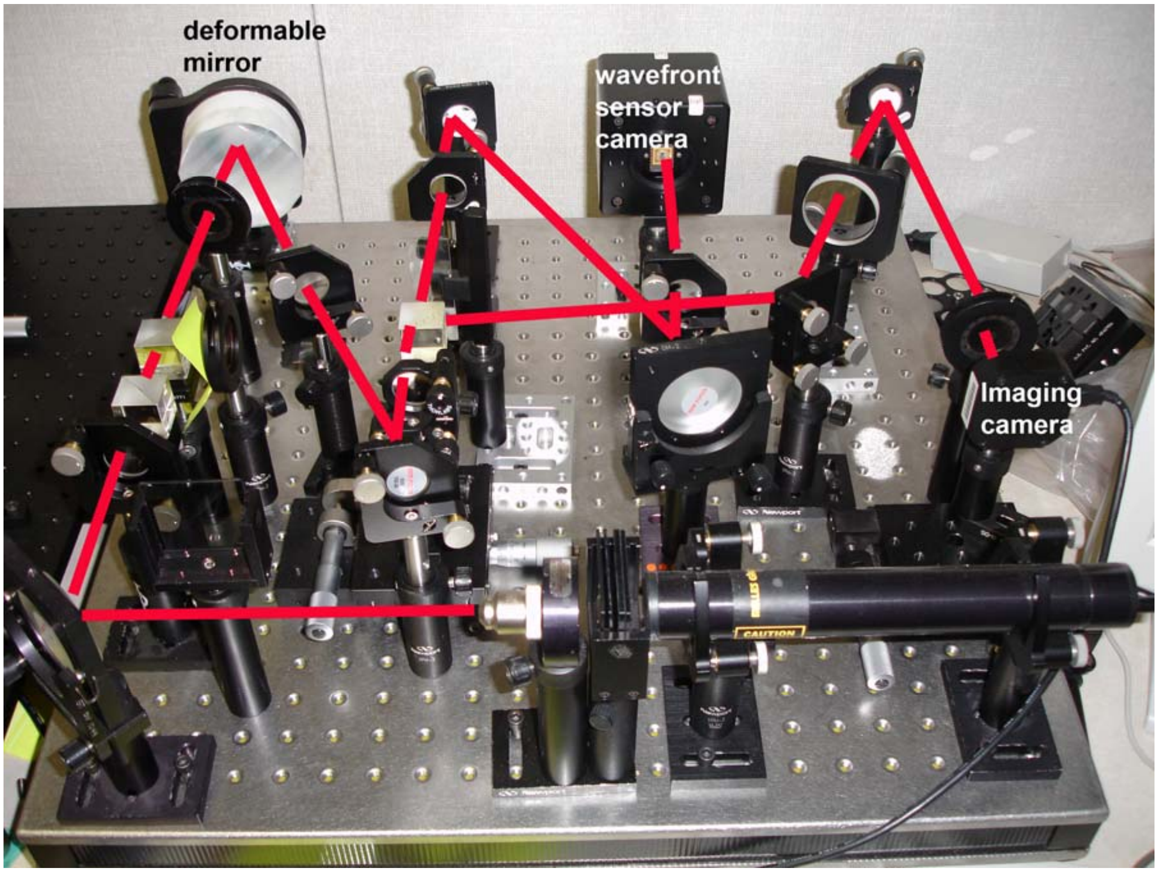


Figure 3. Adaptive optics system as built for laboratory testing. Deformable mirror is located in the upper left (with cover on), the wavefront sensor and camera is in the top center, and the imaging camera is in the lower right just above the laser source.

The entire optical system fits on a 24 inch square breadboard. This system was used with a tip/tilt mirror previously with an order of magnitude increase in Stehl on several astronomical sources, demonstrating its functionality. Although this system cannot obtain the performance of larger bulky systems that are finely tuned for each telescope, it is an inexpensive lightweight option for dramatic improvements in some applications. The 37 element OKO DM is capable or correcting 10 modes allowing this small inexpensive AO system to provide a substantial correction.

Initial testing on the system was performed by slightly misaligning the optics and allowing the reconstructor to correct the wavefront aberrations. Figure 4 shows the aberrated point spread function (PSF) from the misaligned optical system on the far left, while the AO corrected PSF is in the center. Cross sections of each image are displayed on the far right image to show the increased energy density. There was a three-fold increase in peak energy intensity, although only small magnitude aberrations from misalignment were tested.

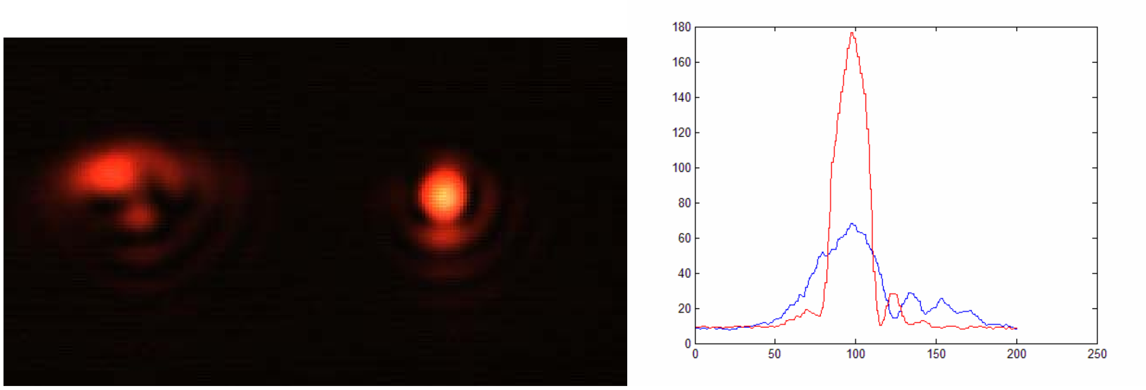


Figure 4. Aberrated PSF (left), AO corrected PSF (center) and cross section cuts (right).

3. ATMOSPHERIC SIMULATOR USING LIQUID CRYSTAL SPATIAL LIGHT MODULATOR

The Noll paper[6] describes using Zernike polynomials for atmospheric turbulence characterization. Using the mathematics around this approach, a real simulator was developed using a Liquid Crystal (LC) Spatial Light Modulator (SLM). Matlab software was written to control the LC SLM to create arbitrary wavefront shapes based on atmospheric aberration parameters, including sampling diameter and Fried's parameter.

Figure 3 shows two beam splitters on the far left of the image. This allows a light path to travel from the source laser after collimation to the aberration simulator testbed shown in figure 5. After the aberration is created, it is fed back into the second beam splitter where it continues to propagate through the AO system. Also shown in figure 5 is a fast steering tip/tilt mirror. The optics system can be modified to include the tip/tilt mirror in the aberration inducing testbed.

The aberration testbed was designed to characterize both the spatial and temporal performance of any AO system. The spatial performance is tested by using the LC SLM to place aberrations either statically or dynamically up to 30 Hz. The AO system will be characterized by determining the degree of correction with respect to the desired or perfect wavefront. The temporal response of the AO system will be tested by setting up a similar aberration system with the tip/tilt mirror and LC SLM. High speed correction can be tested.

The specific LC SLM was manufactured by Holoeye Photonics, AG. It is an 832 x 624 pixel π phase change device capable of operating at up to 30 Hz. It operates as a computer monitor, allowing software to be written to place an 'image' on the device. The images consist of a series of black and white bands that correspond to a phase of either 0 or π. This device creates a phase only change allowing wavefront shaping. Fourier filtering is required to block the higher and lower order modes transmitted through the system. Figure 6 shows a screenshot of the Matlab software and a sample aberration pattern. The aberrations from the testbed can be varied in scale, speed and order for purposes of full AO system characterization. Large tilt is shown in the generated aberration inset in figure 6, as the LC SLM requires a large spot movement to separate the mode orders.

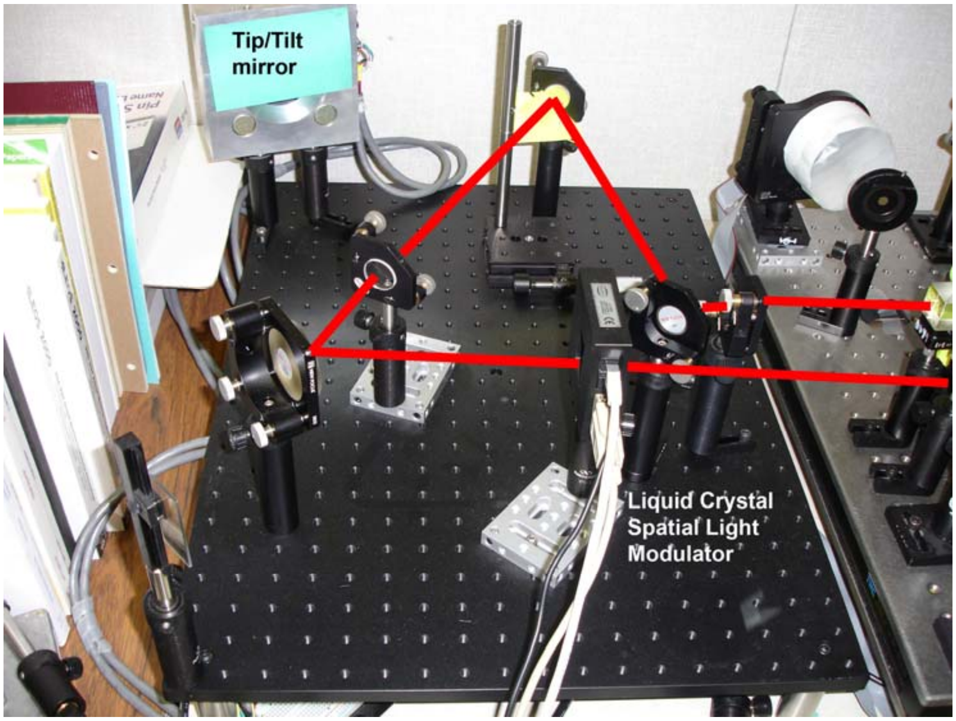
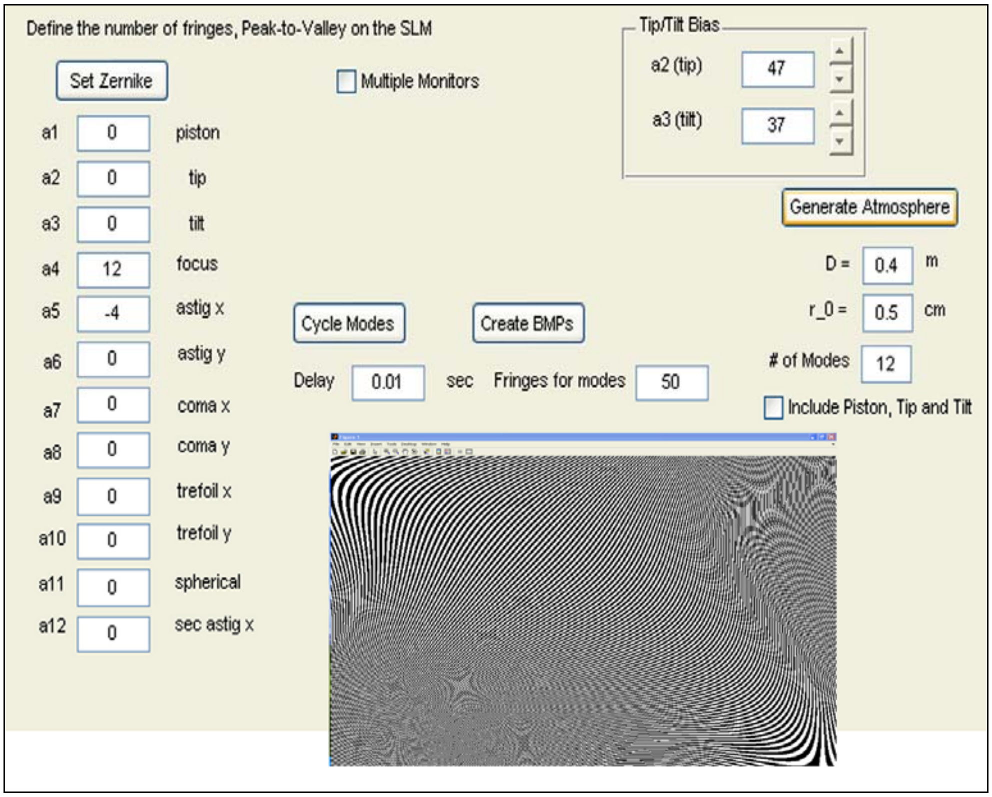


Figure 5. Aberration testbed consisting of reconfigurable combination of liquid crystal spatial light modulator and fast steering tip/tilt mirror.



Define the number of fringes, Peak-to-Valley on the SLM

a1	0	piston
a2	0	tip
a3	0	tilt
a4	12	focus
a5	-4	astig x
a6	0	astig y
a7	0	coma x
a8	0	coma y
a9	0	trefoil x
a10	0	trefoil y
a11	0	spherical
a12	0	sec astig x

☐ Multiple Monitors

Delay 0.01 sec
Fringes for modes 50

Tip/Tilt Bias
a2 (tip) 47
a3 (tilt) 37

D = 0.4 m
r_0 = 0.5 cm
# of Modes 12
☐ Include Piston, Tip and Tilt

Figure 6. Screenshot of Matlab software to generate atmospheric aberrations with inset of sample aberration pattern.

4. SUMMARY OF WORK

The Naval Research Laboratory adaptive optics system has been rebuilt to allow full characterization for implementation with the large lightweight telescope upgrades at the Naval Prototype Optical Interferometer. Preliminary testing shows correction of low order aberrations, including intentional misalignment of optics in the adaptive optics system. Additionally, a novel aberration testbed was constructed employing a Liquid Crystal Spatial Light Modulator based on atmospheric aberration simulation models. These two testbeds allow any aberration generation and adaptive optics correction for full characterization of either system.

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