OPEN-LOOP WOOFER-TWEETER CONTROL ON THE LAO MULTI-CONJUGATE ADAPTIVE OPTICS TESTBED

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ABSTRACT

Advances in micro deformable mirror (DM) technologies such as MEMs, have stimulated interest in the characteristics of systems that include a high stroke mirror in series with a high actuator count mirror. This arrangement is referred to as a woofer-tweeter system. In certain situations it may be desirable or necessary to operate the woofer DM in open-loop. We present a simple method for controlling a woofer DM in open loop provided the device behaves in an approximately linear fashion. We have tested a mirror that we believe meets our criterion, the ALPAO DM52 mirror. Using our open-loop method we fit several test Kolmogorov wavefronts with the mirror and have achieved an accuracy of approximately 25 nm rms surface deviation over the whole clear aperture, and 20 nm rms over 90\% of the aperture. We have also flattened the mirror in open loop to approximately 11 nm rms residual.

1. MOTIVATION

1.1. The MCAO Testbed

The Lab for Adaptive Optics (LAO) currently has a testbed dedicated to the development of two key AO technologies for large telescopes (called multi-conjugate AO (MCAO)\textsuperscript{1} and multi-object AO (MOAO)). Both of these technologies take advantage of tomographic reconstructions using multiple guidestars (a.k.a. reference sources).\textsuperscript{2} In particular, MCAO attempts to achieve a high strehl over a large field of view (FOV) by accounting for anisoplanatism, using multiple deformable mirrors at optical conjugates. MOAO attempts to achieve very high strehls over small FOVs embedded in larger uncorrected fields. First results from the testbed were shown in Ammons 2006.\textsuperscript{3} Recent results have demonstrated the effectiveness of tomography at finding the layers of turbulence, and high strehls have been achieved with both MCAO and MOAO.

The testbed uses three optically addressed spatial light modulators (SLMs) from Hamamatsu Photonics. The SLMs allow us to have nearly 600,000 control elements, far more than any current MEMs. SLMs have been used with some success in the biological sciences (for example, a demonstration is described in Awwal 2003).\textsuperscript{4} Because their stroke is limited to approximately 1 wavelength deviation (about 650 nm on the testbed) and we would like to avoid phase-wrapping, we are incorporating a high stroke mirror into the testbed both to eliminate the need for the SLMs to phase wrap, and to test possible AO configurations for future systems called “woofer-tweeter” setups.

Taking an analogy from audio technology, the woofer-tweeter configuration in AO refers to the pairing of a higher resolution DM that has small stroke together with a high stroke (and consequently low resolution) DM called a woofer. Though our testbed currently uses SLMs, woofer-tweeter combinations will also be useful for MEMs DMs. In addition to our lab, similar architectures are being studied at U. Victoria\textsuperscript{5} and at NUI Galway.

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1.2. Design Considerations

We created a model of the ideal woofer DM by considering the influence functions to be an array of Gaussians that add linearly. The ideal DM was configured with as few as 5 actuators across and as many as 9 across. Using wavefronts measured on the testbed, we then tried to fit these shapes with our simulated DMs in software. It was determined that a mirror of at least 6-7 actuators across was necessary to avoid phase wrapping which occurs any time peak-to-valley (P-V) aberrations exceed 650 nm on our testbed. Fig. 1 shows an example of one of the simulations. We looked into several mirror options on the market, starting with a small electrostatic device. Due in part to the complex nature of the aberrations we are trying to correct, and the high predictability we need for open-loop performance, we eventually settled on an ALPAO DM52 mirror. The importance of this high predictability (linearity) will be discussed below.

2. THE “WOOFERFIT” LINEAR SUPER-POSITION METHOD

We have put together some simple software for controlling a woofer-tweeter system in open loop (schematic shown in Fig. 2). We call the routine that produces the open loop command signals for the mirror “Wooferfit”. Wooferfit runs after the tomography reconstructor has determined the turbulent layers in the volume. We put the low order components of the ground layer wavefront on the woofer.

Wooferfit uses a simple linear super-position method to determine the commands which we will detail below. This method makes the important assumption that the DM is approximately linear with input voltage commands and that the response functions superimpose linearly. Obviously, due to hysteresis effects and force cross-coupling through the mirror face sheet, most DMs will not meet this requirement. The ALPAO DM52 was designed with reduction of these effects in mind.

The first step in our open-loop control process is to obtain good representations of the actuator influence functions using an interferometer. Then, given a mirror with number of actuators $n$, the cross-talk matrix $R_{ij}$, is an $n$ by $n$ sized array generated from:
where \( r_i(x) \) are the influence functions over the mirror surface \( x \), previously measured when a unit of voltage is applied to actuator \( i \). The voltage commands \( a_i \) to the DM controller device are simply:

\[
a_i = R_{inv} \cdot \int r_i(x) \cdot \phi_g(x) dx
\]  

and the wavefront will be given by:

\[
\phi_w(x) = \sum_i a_i \cdot r_i(x)
\]

3. RESULTS

The particular ALPAO DM52 mirror we have in the lab has about a 133 nm rms focus shape when initially powered on but with no commands sent. In order to generate a flat shape we measured and inverted this wavefront and ran it through Wooferfit to generate flattening commands. Our first attempt at flattening the DM52 in open-loop resulted in a residual of approximately 11 nm rms of surface flatness deviation over the full clear aperture of the mirror.

We then tried to fit a typical Kolmogorov wavefront. The testbed uses etched glass Kolmogorov phase plates as turbulence generators. The phase plates are meant to simulate a normal atmosphere’s worth of wavefront aberration. We measured the wavefront using a set of Shack-Hartmann wavefront sensors. After doing a tomographic reconstruction of the estimated volume, there is a residual on the ground layer with approximately 250 nm rms tip/tilt removed wavefront error. We then fit this Kolmogorov wavefront with the ALPAO DM52 using Wooferfit. We compared the surface of the mirror as measured by a Zygo interferometer to the wavefront
generated by the tomography software. Our comparison shows a $25 \text{ nm rms}$ disagreement between the ALPAO DM52 and the Wooferfit predicted shape over the clear aperture (see Fig. 3 above). The fit was noticeably better within the central portion of the mirror and when apertured down to 90% of the clear aperture the agreement was roughly $20 \text{ nm rms}$.

It is important to note that these results are significant because they represent open-loop go-to control of the surface without the benefit of feedback from residual wavefront measurements. Hence these results are applicable to systems which need to run open-loop like MOAO configurations mentioned earlier.

4. CONCLUSION

We have tested the suitability of the ALPAO DM52 as a woofer DM and have shown it has promising open-loop characteristics. Initial results look good for woofer-tweeter implementation in our MCAO testbed.

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