Novel scheme for enhancing beam control in adaptive optics

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Algorithms based on multichannel filtering techniques substantially improve wavefront reconstruction in adaptive optics applications.

As an aspect of aerospace engineering, adaptive optics (AO) refers to the use of deformable mirrors (DM), driven by active control loops that employ feedback wavefront sensor measurements to compensate for turbulence-induced phase distortion of optical waves propagating through the atmosphere. In classical AO systems, control loops have fixed gains based on conjectures concerning turbulence statistics. They are not adaptive in the sense that the term is used in the control and filtering literature, where it refers to updating gains in real time.

Adaptive compensation is needed because wind velocities and turbulence strength can change rapidly. Any fixed-gain reconstruction algorithm is far from optimal. Recent experiments have demonstrated a new control scheme for AO. The system, developed at the University of California, Los Angeles, in collaboration with researchers at the Air Force Research Laboratory, was tested at the Atmospheric Simulation and Adaptive-optics Laboratory Testbed (ASALT), located at the Starfire Optical Range, Kirtland Air Force Base. The new algorithms, based on multichannel adaptive filtering techniques, improve wavefront reconstruction through combined spatial and temporal prediction.

As shown in Figure 1, the adaptive control loop augments a classical AO loop to enhance beam control and imaging through turbulence. High-fidelity wave-optics simulations of directed-energy systems show significant improvement in Strehl ratio and tracking jitter.1, 2 For the first time, experimental applications confirm this improved performance.3

A generic AO problem in directed-energy weapons is shown in Figure 2. The AO system pre-compensates the outgoing high-energy laser for the wavefront error induced by atmospheric turbulence so that it forms a fixed, tight spot on the target. The control system uses reflections from a beacon, created by illuminating the target with a lower-energy laser, to determine the commands to the deformable mirror that cancel the turbulence-induced phase distortion. Such applications led to development of the ASALT facility. Figure 3 offers a schematic diagram of the ASALT optical system.

Experiments at ASALT evaluated the performance of the quasi-adaptive version of the adaptive control loop. The first

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Figure 3. ASALT optical system. The experiments described employed the Self-Referencing Interferometer Wavefront Sensor (SRI WFS), an innovative sensor under development at the Starfire Optical Range.

Table 1. Average closed-loop Strehl ratios for 1000 frames.

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<tr>
<th>Control Loop</th>
<th>Average</th>
<th>Std Dev</th>
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<tbody>
<tr>
<td>Classical AO</td>
<td>0.2769</td>
<td>0.0975</td>
</tr>
<tr>
<td>Adaptive Control</td>
<td>0.4057</td>
<td>0.0811</td>
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</table>

150 modes from a set of frequency-weighted deformable-mirror modes were used by the adaptive control loop. Initially, 3000 wavefront sensor frames were employed to identify the adaptive filter gains. The performance of the adaptive controller was then evaluated on 1000 frames that were independent of those used for identification.

For purposes of comparison, the same experiment was performed with only classical AO and track loops, also using the first 150 deformable-mirror modes and the same 1000 frames for evaluation. Table 1 lists the average closed-loop Strehl ratios and standard deviations for the scoring camera images. For the turbulence scenario examined, the adaptive controller provided a nearly 50% increase in Strehl and reduced the variability by more than 15%. Figure 4 shows sample images from the evaluation sequences, further demonstrating the benefits of the adaptive controller.

Continued testing of these new control methods is planned, with a focus on implementing the fully adaptive version of the algorithm that updates the control loop gains on a frame-by-frame basis.

Researchers at UCLA and AFRL were supported by grants from the Air Force Office of Scientific Research and the High Energy Laser Joint Technology Office.

Figure 4. Representative closed-loop scoring camera images further indicate the benefits of adaptive compared with classical control.

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