Mitigation of Deep Turbulence Effects with SPGD Based Adaptive Optics System

Ernst Polnau\textsuperscript{1}, Mikhail Vorontsov\textsuperscript{1}, and Rodolfo Llinás\textsuperscript{2}

\textsuperscript{1}Intelligent Optics Laboratory, School of Engineering, University of Dayton, 300 College Park, Dayton, OH 45469-2951
\textsuperscript{2}Department of Physiology and Neuroscience, New York University School of Medicine, New York, NY 10016
epolnau1@udayton.edu

Abstract: A low-cost AO system designed to be installed into an amateur astronomical telescope was tested in deep turbulence conditions. The results demonstrate potentials of the technique for star-image quality improvement in amateur astronomical telescopes.

OCIS codes: 010.1080 Adaptive optics; 010.1285 Atmospheric correction; 010.1330 Atmospheric turbulence; 350.1260 Astronomical optics

1. Introduction

Correction of wave front aberrations caused by atmospheric turbulence using adaptive optics (AO) is still a challenge for amateur astronomical community due to high-cost of AO systems that are currently used in large- and middle-class specialized professional telescopes. This high AO cost is in part due to use of still expensive deformable mirrors based on push-pool type piezo-actuators and wavefront sensors equipped with fast framing camera and wavefront phase reconstruction signal processing electronics. The major goal of this experimental study is to evaluate potentials for an inexpensive and simple AO system architecture that can be used in amateur astronomical telescopes for mitigation of quasi-static aberrations of telescope’s optics and atmospheric turbulence effects. The AO system is based on low-cost AO components: bimorph deformable mirror with 31 actuators, stack of high-voltage amplifiers and PC-based SPGD software (all from Optonicus LLC \cite{1}), and such off-the-shelf elements as beam splitter, lenses and photo-multiplier.

The AO system was used for correction of an image of a green laser beacon located over 7 km near-horizontal propagation path under various atmospheric turbulence conditions. The quasi-static aberrations were introduced by a glass window the beacon light passed through before entering the 9.25” Schmidt-Cassegrain telescope of the system.

2. Experimental Setup

The experimental setting (Fig. 1) includes a 7 km horizontal atmospheric path between a shelter on the roof of the VA Medical Center (VAMC) in Dayton and an optical table next to a single-glass window inside Intelligent Optics Laboratory located on the UD campus. A Scintec BLS2000 scintillometer is available to measure the strength of the atmospheric turbulence along the optical path of the test range.

![Fig. 1. Optical setup showing the adaptive optical system, the telescope, and the beacon used to simulate a star.](image-url)

In the shelter on top of the VAMC building a green laser beacon with a wavelength of 532 nm is installed which is used to simulate a star like object. The beacon has an aperture size of 26 mm and transmits a Gaussian shaped collimated laser beam in direction of the adaptive optical receiver setup on the optical table in the Intelligent Optics Laboratory. Due to diffraction the diameter of the of the laser beam at the receiver telescope of the setup is about
1 m. The height of the laser beam above ground varies from between 40 m at the VAMC and 15 m at the laboratory on the UD campus.

The receiver telescope is a Celestron Schmidt-Cassegrain telescope with a focal length of 2350 mm and an aperture of 235 mm. A lens \(L1\) collimates the received beam from the telescope. The mirror \(M1\) redirects the beam and an optical relay consisting of lenses \(L2\) and \(L3\) projects the laser beam onto the surface of the 31-channel deformable mirror \(DM\). From the deformable mirror the beam is reflected towards the focusing lens \(L4\). A beam splitter \(BS1\) divides the beam with one part focusing on a \(CCD\) camera and the other part focusing onto a pinhole in front a photomultiplier (Thorlabs PMM02).

The signal of the photomultiplier was used as input metric for a PC based stochastic parallel gradient descent (SPGD) controller which controlled the deformable mirror \(DM\). The closed loop iteration rate of the SPGD controller was 10 kHz.

3. Results

Tests were done comparing the metric (photomultiplier signal) with and without closed loop SPGD operation. This was done by performing 100 test runs where the metric during each test run was recorded. Each test run was 20 seconds long during which the closed loop AO was switched off for the first 10 seconds and switched on for the next 10 seconds. Fig. 2(a) shows the resulting diagram where the development of the metric averaged over all 100 runs is shown. An improvement of the averaged metric by a factor of 2.3 can be seen indicating an improvement in spot quality and partial correction of wavefront aberrations.

![Fig. 2. (a) Averaged metric development for 100 SPGD off-on runs (b) Averaged spot while SPGD off (c) Averaged spot while SPGD on.](image)

In Fig 2(b) the averaged spot on the CCD camera during a 10 second period with open loop is seen while in Fig. 2(c) the averaged spot during 10 second with closed loop operation is seen. An increased concentration of the intensity distribution in the center of the spot during closed loop SPGD operation is visible. The scintillometer measured the turbulence refractive index structure parameter \(C_n^2\) as \(8 \times 10^{-12}\) during the experiment. A rerun of the experiment during a time when \(C_n^2\) was \(1 \times 10^{-15}\) gave similar results.

Further experiments were conducted to verify that the AO system works with the power levels a 100 cm-amateur astronomical telescope is expected to receive from stars. Closed loop SPGD operation showed improvements of the signal with received powers lower than 1 nW which suggests that a 100 cm-astronomical telescope equipped with the proposed AO system could be used with at least the 50 brightest stars in the sky.

Analysis of the convergence behavior of the averaged control signals for the deformable mirror during closed loop SPGD operation showed that the AO system corrected also the static wavefront distortions introduced by the glass window in the optical path in addition to the dynamic aberrations caused by atmospheric turbulence.

4. Conclusions

The experiments demonstrated the feasibility using the designed AO system for the mitigation of wavefront aberrations for propagation of light through thick atmospheric turbulence. In thin turbulence – as is the case for vertical propagation paths during observation of astronomical object with ground based telescope – the performance should be even better. Amateur astronomers often don’t have easy access to the top of high mountains where the turbulence is lower and have therefore to cope with strong turbulence caused aberrations during observations. The presented results show that an amateur telescope equipped with the developed low-cost AO system has the potential to mitigate the effects caused by atmospheric turbulence as well as static aberrations within the telescope itself.

Acknowledgement: This work was supported by the US AFOSR MURI Contract FA9550-12-1-0449.

5. References