Seeing estimations from adaptive optics telemetry

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Abstract

Motivation: Estimating atmospheric turbulence parameters is essential for assessing the performance of an adaptive optics (AO) system aiming to correct the effects of Earth's atmosphere on the seeing of an observed astronomical object. One such system is the adaptive optics system of the Auxiliary Telescopes of the VLTI, NAOMI. Making use of a Shack-Hartmann (SH) wavefront sensor coupled with a deformable mirror (DM) and control loop, a dynamic correction of the wavefront deformations caused by atmospheric turbulence can be achieved. Treatment of the telemetry data, associated with the correction, is used to achieve a reconstruction of the Fried parameter and outer scale allowing for an estimation of the performance of the AO system.
Methods: The performance of the NAOMI system was first estimated through simulation of the response of the SH sensor to an atmosphere, based on the von-Kármán model of turbulence. A reconstruction of the original atmosphere was achieved from the response of the artificial sensor, through the use of an adapted fitting algorithm (1) which accounts for the effects of the non-orthogonality of the derivative of the modal Zernike basis, known as cross-talk, as well as the measurement noise from various sources (ex: photon noise). Real data analysis followed the simulation work, turbulence parameters were once again obtained from fitting of the modal coefficients, which were produced from the coupled response of the wavefront sensor and DM. The data from the 4 sensors of NAOMI was compared to find agreement between the estimations. The error of the data was estimated from a Monte Carlo error estimation, from the distribution of the existing variances.

Results: Estimates for the system simulation point to a convergence of the Fried parameter to the screen generating values within 8 seconds of evolution, with an error of 0.51 % to the introduced parameter. The outer scale never shows a convergence to the desired threshold of error, steadily decreasing in error to 21 % error in a 20-minute frozen flow simulation.

Real data estimates show a convergence of the Fried parameter in the 60 second data samples, as predicted by the simulation, these results were compared with the DIMM estimates, showing a median difference of 0.40% between the two. Agreement in the estimation of the Fried parameter between the various sensors was observed, allowing for the simultaneous coupling of the 4 sensors in turbulence estimations, reinforcing the validity of the calculated values.

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The outer-scale never approaches the mean value of the outer-scale at the Paranal observatory, for data points spreading 3 years of observation. These results point to an insufficient diameter of the Auxiliary Telescopes (1.8 meters in diameter), making the telescope effectively blind to this second parameter and as such correspond to a measured turbulence more closely related to the Kolmogorov model.

References

(1) P. Andrade, P. J. Garcia, C. M. Correia, J. Kolb, and M. I. Carvalho, "Estimation of atmospheric turbulence parameters from shack-hartmann wavefront sensor measurements," Monthly Notices of the Royal Astronomical Society, vol. 483, pp. 1192–1201, 2 2019.