Predictive Learn and Apply: MAVIS application - Apply

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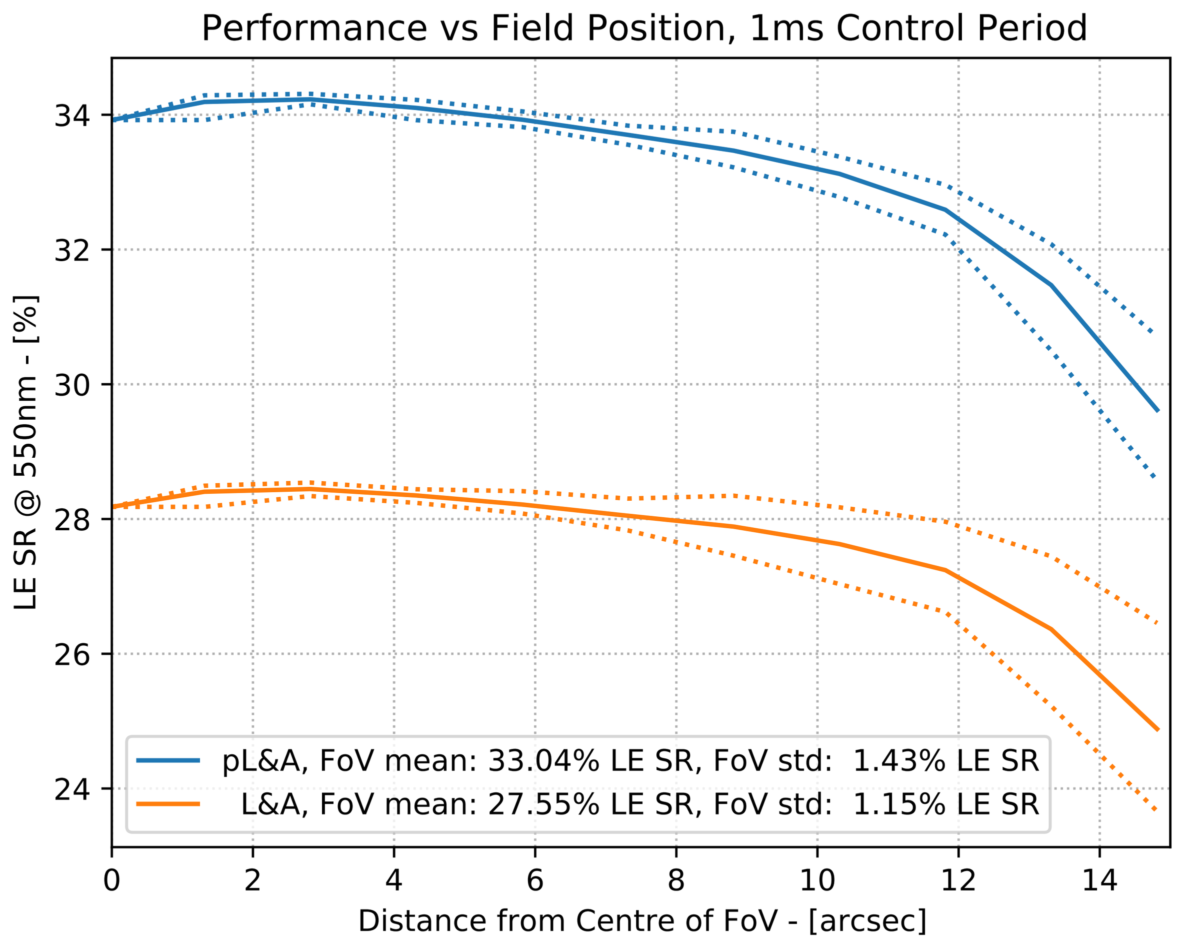
Abstract

The MCAO Assisted Visible Imager and Spectrograph (MAVIS) under design for UT4 at VLT promises wide-field AO corrected science in the visible spectrum. To meet the tight error budget of MAVIS, robust and effective tomographic reconstruction techniques are required for the control of the ~5000 actuators across 3 DMs, from the ~19000 measurements from 8 LGS.
Learn and Apply proves to be an appropriate reconstruction scheme, and the extension of Learn and Apply to utilise the predictable nature of frozen-flow turbulence is capable of further improving the efficacy of this method. We derive the Predictive Learn and Apply (**pL&A**) reconstructor and demonstrate its performance in MAVIS based end-to-end simulations.



Modifying L&A for Prediction

Classical L&A (Vidal 2010) is formulated as the Linear Minimum Mean Square Error (LMMSE) estimate of the measurements in the directions of the scientific targets, z_k, based on the true measurements, s_k:

$$\hat{z}_k = \langle z_k s_k^T \rangle \langle s_k s_k^T \rangle^{-1} s_k$$

The conceptual change required to make L&A *predictive* is to instead compute the estimate at a point forward in time, determined by the (non-integer) delay d:

$$\hat{z}_{k+d} = \langle z_{k+d} s_k^T \rangle \langle s_k s_k^T \rangle^{-1} s_k$$

This is achieved by computing the elements of the covariance matrix $\langle z_{k+d} s_k^T \rangle$ using frozen-flow shifted coordinates at each layer of turbulence. In this way, pL&A can be considered as a slope-based Spatio-Angular predictive reconstruction scheme (see Correia 2010) The process of identifying the frozen-flow turbulence parameters is discussed in our companion paper by Zhang et al.

pL&A in POLC

Pseudo open-loop control (POLC) is an effective and demonstrably stable control scheme, perfectly suitable for L&A, and pL&A. POLC is based on defining the open-loop control law (as if the DMs were not seen by the WFSs), then embedding this into a closed-loop controller by assuming that the DMs are instantaneous and linear in their response to a command signal.
The pL&A open loop control law is:

$$u_k = \underbrace{(D_z^T D_z + \alpha \mathrm{I})^{-1} D_z^T \langle z_{k+d} s_k^T \rangle \langle s_k s_k^T \rangle^{-1}}_{\triangleq R} s_k \,,$$

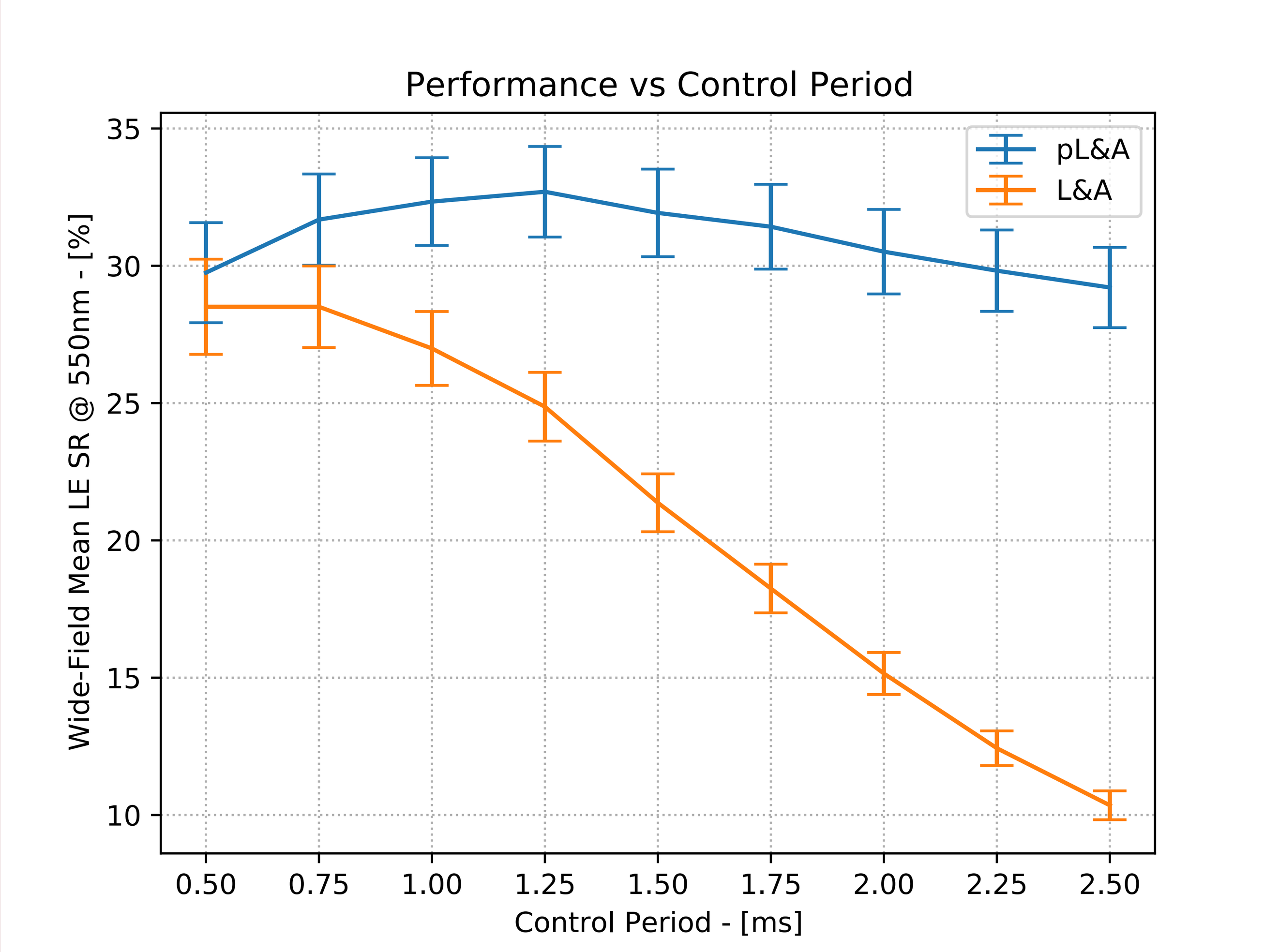
which after embedding into POLC and accounting for a two-frame delay (the arbitrary delay case is given in the manuscript) is:

$$\begin{bmatrix} u_k \\ u_{k-1} \end{bmatrix} = \begin{bmatrix} (1-g) & gRD_s \\ \mathrm{I} & \mathbf{0} \end{bmatrix} \begin{bmatrix} u_{k-1} \\ u_{k-2} \end{bmatrix} + \begin{bmatrix} gR \\ \mathbf{0} \end{bmatrix} s_k^{\mathrm{cl}},$$

where D_s and D_z are the interaction matrices of the true measurements and virtual measurements respectively, $g \in (0,1)$ is a scalar which determines the cut-off frequency of the unity-gain open-loop IIR filter, $\alpha > 0$ is the Tichanov regularisation parameter, u_k are the DM commands based on the measurements obtained at time k, and s_k^{cl} are the closed-loop measurements.

Slowing the AO Loop

- The return flux from LGSs is limited by the availability of sodium in the upper atmosphere,
- These sodium levels vary drastically seasonally,
- Reducing the AO control frequency increases the photons collected per WFS measurement (and thus the SNR),
- Slowing the AO loop also results in more servo-lag error,
- Predictive control mitigates servo-lag error, allowing high performance with a slower AO loop,
- **Therefore, predictive control allows us to combat low sodium flux levels by decreasing the AO loop speed.**



- Peak performance of L&A occurs at ~1300Hz,
- Peak performance of pL&A occurs at ~800Hz,
- The worst performance of pL&A (at 400Hz) is higher than the peak performance of L&A (at 1300Hz)
- Slowing the loop by a factor of >2 would increase the robustness against seasonal variations of sodium LGS return flux, as well as having an effect on sky-coverage.

Conclusions

Learn and Apply is a promising method for building MCAO tomographic reconstructors in systems such as MAVIS. The addition of a predictive step in the L&A reconstructor provides an additional gain at no increase in online computational load. End-to-end numerical simulations suggest an improvement of approximately 37nm RMS wave-front error averaged over the MAVIS science FoV.

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MAVIS, for more information visit
http://mavis-ao.org/mavis/