MOAO real-time LQG implementation on CANARY

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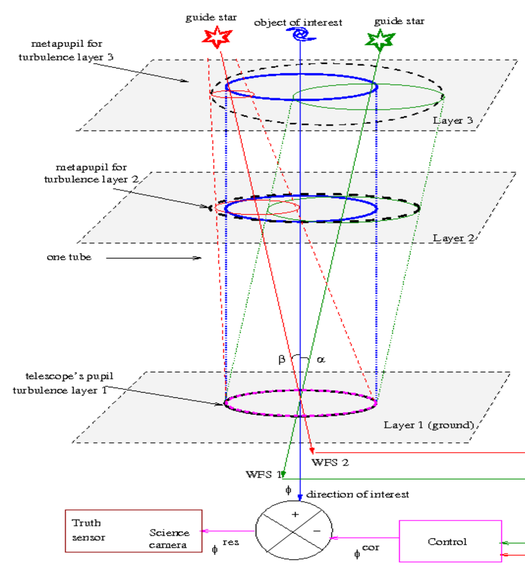
CONTEXT

Advances on LQG AO control

- LQG control accounts for spatial and temporal priors (expressed through explicit models) [1]
  - Better performance
  - Better stability and sensitivity to noise
- Flexible control
  - SCAO and WFAO, open and closed loop config [2]
  - Turbulence + Vibrations rejection [3]
- Woofer-tweeter [4]
- Large degrees of freedom [5], [6]
- Experimental demonstrations
  - Vibration filtering [7]
  - WFAO validation on WFAO testbed HOMER [8]
- Canary phase B constitute a perfect framework for the first LQG control on-sky demonstration

Tomographic AO description



$$y^{ngs,i} = D^{ngs,i} M^{ngs,i} \varphi + w^{ngs,i}$$

NGS WFS matrix — Cylindrical or conical projection matrix

$$y^{lgs,i} = D^{lgs,i} M^{lgs,i} \varphi + w^{lgs,i}$$

LGS WFS matrix (deals with Tip/Tilt indetermination)

$$\phi = M^{obj} \varphi$$ Resulting turbulent phase

On-axis cylindrical projection

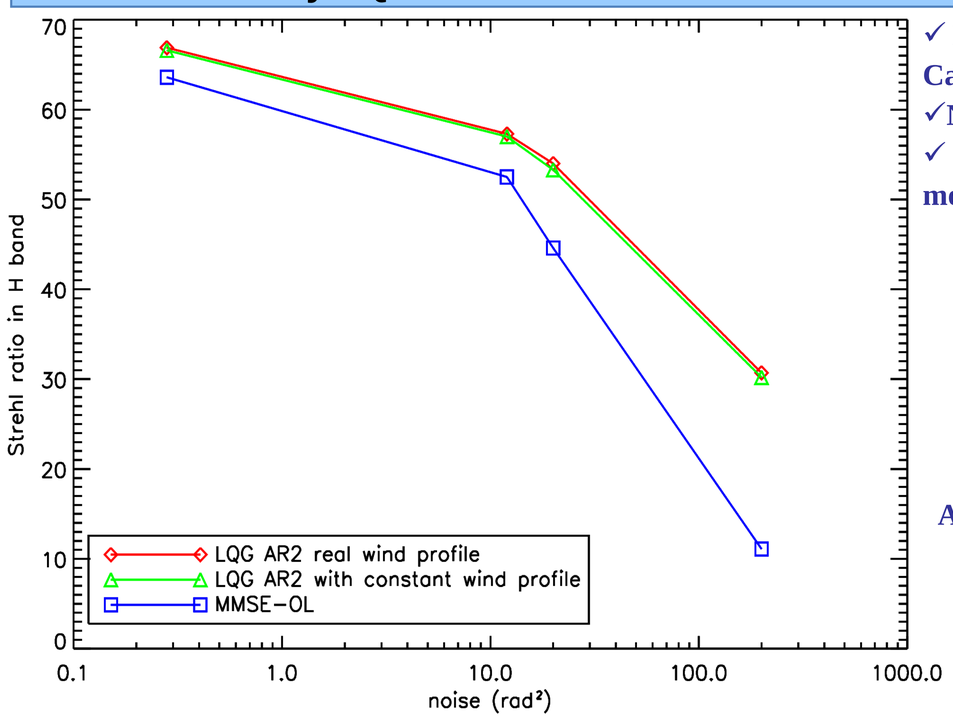
$$\phi^{cor} = N u$$ Correction phase

Influence matrix

$$\phi^{res} = \phi - \phi^{cor}$$ Residual phase

LQG MODELING AND SIMULATION RESULTS

Canary LQG MOAO Performance: Simulation results



✓ **Perfect prior on System Calibration & Cn2 profile**
✓ **No vibrations**
✓ **Strehl Ratios for different modelisations:**
- **LQG AR2 derived from true wind profile, Wind = [7.5, 12.5, 15] m/s**
- **LQG AR2 derived from mean wind profile, Wind = [11.2, 11.2, 11.2] m/s**
- **MMSE-OL**

As a function of: WFS Noise

LQG control robust to wind profile uncertainties
Good performance in low SNR thanks to spatial & temporal priors
Significant improvement compared to static MMSE reconstructor

LQG Control & Disturbance model

- Optimality criterion : minimum variance of the residual phase
- Solution obtained through the Stochastic Separation Principle

$$u_k = P\hat{\phi}_{k+1|k} = (N^T N)^{-1} N^T \hat{\phi}_{k+1|k}$$

$$\hat{\phi}_{k+1|k} = \mathrm{E}[\phi_{k+1} | \mathcal{Y}_k] \text{ where } \mathcal{Y}_k = \{ y_k, y_{k-1}, \dots, y_0 \}$$

conditional expectation ➔ Kalman filtering with explicit dynamical models

- Disturbance = Turbulence + Vibrations $\phi_k = M^{obj} \varphi_k^{tur} + \phi_k^{vib}$
- Vector-valued auto-regressive (AR) processes (of order 2 here)
- We can write this model for a given turbulent layer as:

$$\varphi_{k+1}^{tur,l} = A_1^{tur,l} \varphi_k^{tur,l} + A_2^{tur,l} \varphi_{k-1}^{tur,l} + v_k^{tur,l}$$

- Same model used for the vibrations with resonance peak [4]

$$\varphi_{k+1}^{vib,i} = A_1^{vib,i} \varphi_k^{vib,i} + A_2^{vib,i} \varphi_{k-1}^{vib,i} + v_k^{vib,i}$$

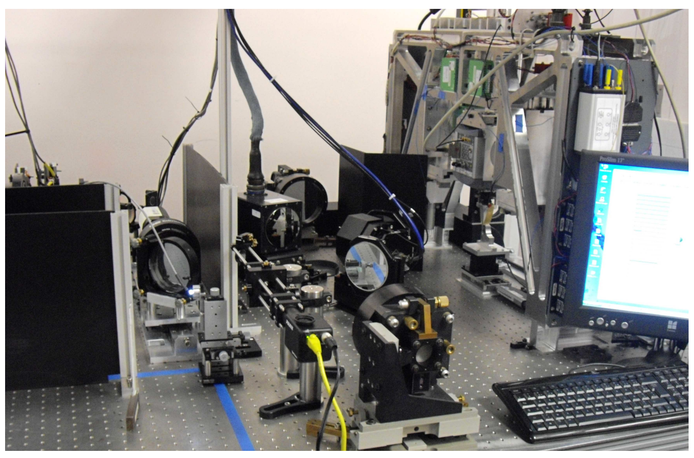
Parameters identified off-line
Separation between Tip/Tilt & High Order in the modeling

LQG INTERFACE STRUCTURE ON CANARY

$$x_k = \begin{pmatrix} \varphi_k^{tur} \\ \varphi_{k-1}^{tur} \\ \phi_k^{vib} \\ \phi_{k-1}^{vib} \end{pmatrix}$$

$$\begin{cases} x_{k+1} = Ax_k + \Gamma v_k & \text{Evolution model} \\ y_k = Cx_k + w_k & \text{Measurement model} \\ \phi_k = C_\phi x_k & \text{Performance output} \end{cases}$$

$$\begin{cases} \hat{x}_{k|k} = \hat{x}_{k|k-1} + H_\infty (y_k - C\hat{x}_{k|k-1}) & \text{Update equation} \\ \hat{x}_{k+1|k} = A\hat{x}_{k|k} & \text{Predictive equation} \end{cases}$$



Vector	Format	Size
x_k	n_x	$2(410+20) = 860$
y_k	n_y	$8 \times 2 \times 72 = 1152$
u_k	n_u	$52 + 4 = 56$

STYC

System and Turbulence identification
Learn of **Learn** & Apply [9]
C_n^2 profile ...

Dynamical parameters identification
Turbulence + Vibrations

Model construction

Kalman gain computation

Computation of M_1, M_2, M_3, M_4

Consistency real-time indicators

Upload Matrices

M_1, M_2, M_3, M_4

DARC

$$\begin{cases} x_{k+1} = M_1 x_k + M_2 (y_k + M_3 u_{k-2}) \\ u_{k+1} = M_4 x_{k+1} \end{cases}$$

$$\begin{cases} M_2 = AH_\infty \\ M_1 = A - M_2 C \\ M_3 = 0 \\ M_4 = (N^T N)^{-1} N^T C_\phi \end{cases}$$

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PERSPECTIVES

- LQG interface is under development
- On-lab tests planned during Winter 2011 & Spring 2012.
- On-sky validation expected during Summer 2012

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