Pyramid Optical Gains tracking using a Convolutive Model

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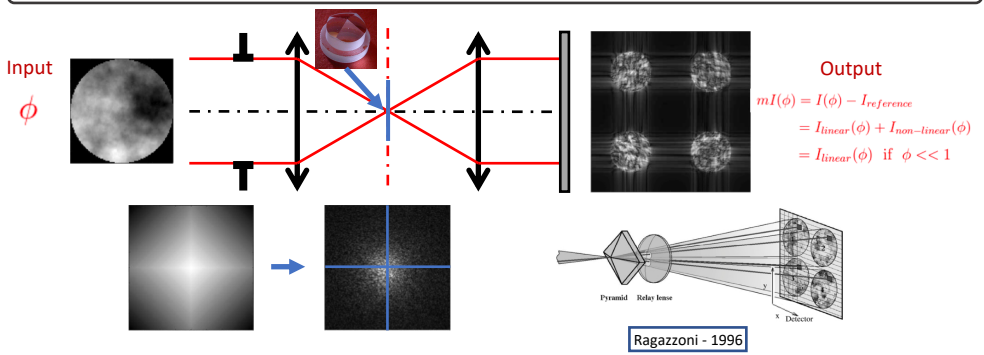
Pyramid wavefront sensor

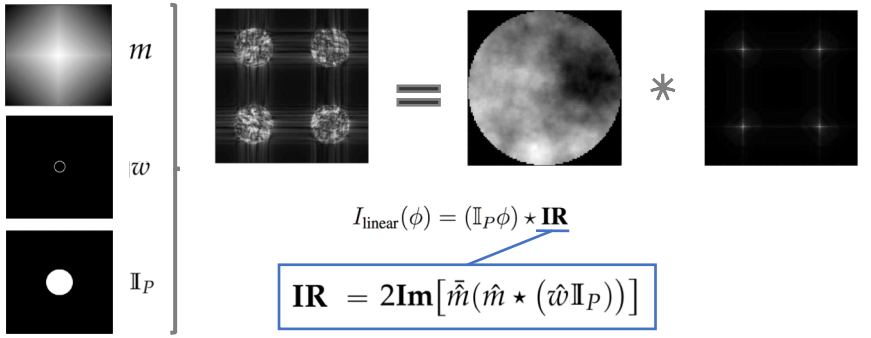
Pyramid wavefront sensor uses a glass pyramid as a phase mask located in a focal plane to achieve **optical Fourier filtering**. The behaviour of this highly sensitive sensor can be theoritically discribed thanks to diffraction theory.



Ragazzoni - 1996

Convolutive model

The entrance pupil geometry, the pyramid shape and the tip-tilt modulation are the given properties that allow to compute analytically the **Impulse Response** of the Pyramid WFS.



$$I_{\text{linear}}(\phi) = (\mathbb{I}_P \phi) \star \mathbf{IR}$$

$$\mathbf{IR} = 2\mathbf{Im}\left[\bar{\hat{m}}(\hat{m} \star (\hat{w}\mathbb{I}_P))\right]$$

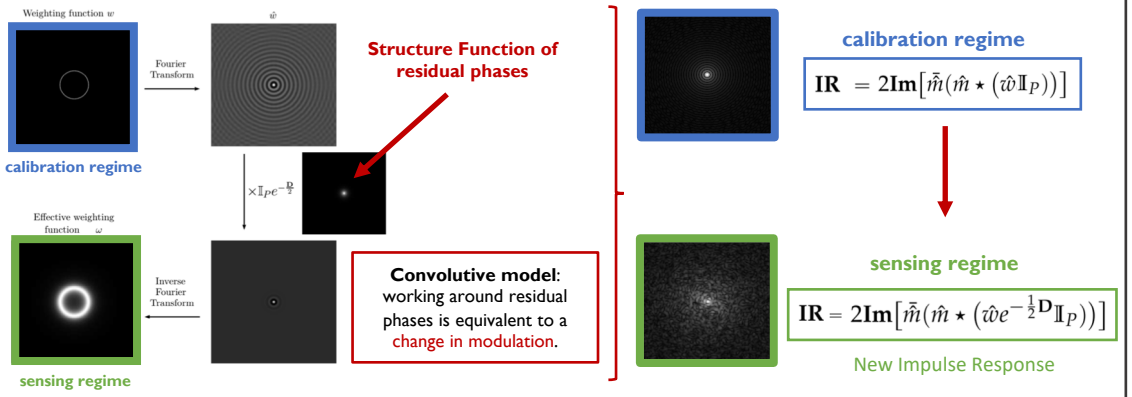
HYPOTHESIS

- Fourier based WFS
  - Small phases approximation
- Linear Model
  - Sliding pupil approximation $\mathbb{I}_P|_{\vec{r}} \approx \mathbb{I}_P|_{\vec{r}-\vec{\epsilon}}$
- Convolutive Model

Wavefront sensing with a Pyramid in presence of residual phases

Pyramid WFS shows a loss of sensitivity while working around a residual phase, known as the **Optical Gains** problem.

The convolutive model allows to compute the new Impulse Response of the system by taking in account the **structure function** of the residual phases.



Optical Gains computation

OPTICAL GAINS DEFINITION

The Optical Gains is a transfert matrix that encodes the change between the sensing regime and the calibration regime

$$iMat_{sensing} = iMat_{calib}.G_{opt}$$

Approximation - the Optical Gains is a diagonal matrix

$$G_{opt} = \begin{bmatrix} G_1 & & 0 \\ & G_i & \\ 0 & & G_m \end{bmatrix} \begin{matrix} \text{modes} \\ \\ \text{modes} \end{matrix}$$

$$G_i = G(\phi_i) = \frac{< mI^{sensing}(\phi_i) | mI^{calib}(\phi_i) >}{||mI^{calib}(\phi_i)||^2}$$

Convolutive model

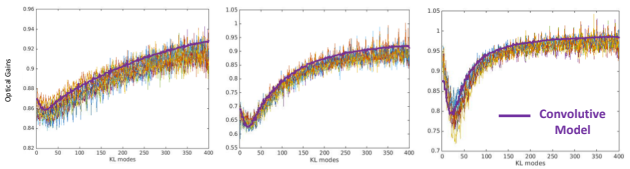
Scalar product between measurements in sensing regime and in calibration regime

$$G_i = G(\phi_i) = \frac{< IR^{sensing} * \phi_i | IR^{calib} * \phi_i >}{||IR^{calib} * \phi_i||^2}$$

Accuracy of the model: comparaison to End-2-End simulation

The accuracy of the Optical Gains prediction by the convolutive model was proven by End-2-End simulations.

Limitations
- Not accurate without modulation
- Slight difference for low-order modes



Next Steps:
- Tests on LOOPS testbed and on Sky (Keck Observatory)
- Robust method to get the structure function (from telemetry?)

References

1 - *Ragazzoni* - Pupil plane wavefront sensing with an oscillating prism - 1996
2 - *Fauvarque et. al* - Kernel formalism applied to Fourier based Wave Front Sensing in presence of residual phases - 2019
3 - *Deo et. al* – A modal approach to optical gain compensation for the pyramid wavefront sensor - 2018