How to exactly describe WFS non-linearities with interaction matrices

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Abstract

Angular resolution of the future ELTs imaging system will depend on the performance of their Adaptive Optics systems, i.e. on the quality of the phase aberrations estimation. This estimation can essentially be decomposed into two parts. The first one is related to noise propagation and is linked to the concept of sensitivity. Such a performance criteria is a matter of optical design optimization which should ensure a high photons efficiency by the Wave Front Sensor (WFS).
The second aspect is related to how the phase is estimated from WFS measurements. To do so, a mathematical operator, called reconstructor, transforms WFS signal into Deformable Mirror (DM) commands. Such an operator may be seen as the inverse function of the 'DM towards WFS' system. To get the most efficient estimation, a description of the WFS/DM as close as possible of the WFS behavior while sensing the phase is needed. Moreover this model has to be easily invertible and also to provide a reconstructor fast enough to be operated in real time. That is why in AO context, methods based on calibration matrices are especially relevant. Unfortunately, such methods prove to be less efficient when working in the non-linear regime of the WFS.

As a consequence, methods have been developed to tackle these effects that may occur during sensing. If analytic reconstructors may be used, such approaches are not always easy to implement. That is why a matricial method, called Optical Gains (OG,) has been developed to compensate the phase underestimation due to non-linearities. This method does improves the performance of AO loop but is still imperfect, especially when non-linearities imply cross-talks between phase modes.
To further improve the reconstruction, the next step is therefore to compute the cross-terms of the gain matrix. However, there is no way, at the present time, to compute the full gain matrix. In this paper, we introduce a numerical tool to build such a matrix that describes precisely the link between WFS signal and the input phase, whether the sensor is working on its linear regime or not. We will show how to calculate it and how to improve phase estimation. We will also present some ways to get it in practice.

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