Petal mode measurement and reconstruction with pyramid wavefront sensor assisted by spatial filtering

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September 2022

Abstract

Context The atmospheric turbulence limits the angular resolution of large telescopes. Adaptive Optics (AO) was proposed to compensate this effect and restore a resolution as close as possible to the diffraction limit promised by large telescope diameters. An AO system requires 3 key components: a deformable mirror in the light path to compensate dynamically for atmosphere, a wavefront sensor (WFS) to measure the atmospheric turbulence residuals on a starlight, a real time computer to compute the correction and control the deformable mirror. We concentrate here on the wavefront sensor. The wavefront sensor needs to be as sensitive as possible to be used on dim stars and cover most of the sky. Due to its sensitivity, the pyramid wavefront sensor (PyWfS) is the most promising wavefront sensor for the next generation of thirty meter class telescopes. But it comes with limitations that we study in this presentation.

Problem :

If the ability of PyWFS is demonstrated for measuring the atmospheric turbulence in itself, which makes mandatory the use of modulation to increase the limited dynamic range, it is unable to measure properly a phase discontinuity in presence of turbulence and modulation.

This causes a new problem with the complex pupils of the thirty meter class telescopes. The pupil shape causes discontinuities of the wavefront measurement to appear. The phasing of the telescope can also create phase discontinuities (M4 on EELT, phaseing of GMT segments ...). Finally the Low wind effect can also add phase discontinuities around the spiders. This results in the so-called petalling effect where the wavefront is well corrected inside one fragment of the pupil but there are piston jumps from one fragment to the other. This mode, if left uncontrolled reduce the resolution by a factor $\sqrt{N_{fragment}}$.

Aims :
The PyWFS sensitivity to petalling varies greatly between its modulated and unmodulated mode. The first aim of this work is to understand the difference in behaviour between these two modes, and to understand why the

PyWFS looses its sensitivity in presence of modulation. The second aim is to propose a solution based on a highly sensitive unmodulated mode specifically for petal control. It would be used as a second path sensor measuring only the phase residuals in tandem with an AO system controlling the turbulence. To improve the PyWFS robustness to residuals we proposed to add a spatial filter. This spatial filtering stage has shown interesting results and allows the unmodulated PyWFS to work in its optimal range despite the phase residuals that would normally degrade the quality of the measurement.

Results :
We present here the linearity of a modulated and unmodulated PyWFS in presence of phase residuals. We present as well the interest of spatial filtering with the PyWFS, with the goal of attenuating the atmosphere residual to the benefit of the petal mode. We finally demonstrate with an E2E simulation the interest of the spatially filtered PyWFS to control petal mode in a closed loop as a second path sensor.