Training and Optimizing the Deep Optics Preconditioner for the Pyramid Wavefront Sensor

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Abstract

The Pyramid Wavefront Sensor (PWFS) (1) is one of the preferred choices to measuring wavefront
aberrations for adaptive optics in highly sensitive astronomical applications. Despite its high sensitivity,
the PWFS offers a limited linear range of operation that can only be extended through the modulation of
the pyramid, which involves additional mechanical and movable parts, complicating the optical setup and
its calibration and operation. Nevertheless, modulation decreases the sensitivity in exchange of the
extended linearity range. Inspired by artificial intelligence techniques, we designed (2) a passive
diffractive layer that acts as an optical preconditioner to the PWFS, with the aim of extending the linearity
range without the need for modulation. The design of the novel Deep Optics PWFS (DWPFS) is obtained
through an End-2-End optimization scheme that involves, firstly, the physical modeling of the optical
propagation path of the modified PWFS up to the measured intensity patterns at the detector level, and
secondly, the mathematical estimation using a linear model. Then, the estimation error is used to feed the
backpropagation through the models to update the diffractive layer. Considering as initial point the PWFS
without modulation, the training process is performed using a variety of wavefront maps from realistic
turbulence models at different strengths, most likely situated in the zone where we want to force the
response of the sensor to become more linear. As shown in Fig.1, simulation results suggest that the
DPWFS excel for estimating turbulence without requiring modulation, being competitive to the PWFS
with modulation. On the other hand, the DPWFS is not benefited from modulation as the

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original PWFS.
In this work, we will show our efforts to understand the importance and impact in terms of linearity and
sensitivity of selecting the training parameters such as the dataset statistics, turbulence range, adding or
not detector or photon noise, enabling beam modulation, calibration set point, and incorporating
experimental constraints.

Keywords: linear range, diffractive layer, end2end optimization