Deep Optics for Wavefront Sensing: Beyond the Pyramid Wavefront Sensor

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Abstract

Our group have recently updated the Pyramid Wavefront Sensor (PWFS) (1) with a diffractive optics layer that acts as an optical preconditioner to the PWFS measurements, under the assumption that the reconstruction is based on a modal/zonal linear least-squares reconstruction stage. The newly Deep Optics PWFS (DWPFS) (2) is designed by using a methodology derived from artificial intelligence techniques based on deep learning, and that have been recently adapted to treat the forward and inverse models of a physical system as being a neural network, where, in this case, the only trainable parameters (or weights) are at the added diffractive optics layer, that has been place at the Fourier plane. With the goal of improving the linearity of the PWFS, we designed a DPWFS using an End-2-End training scheme as seen in Fig.1, where we used a collection of known wavefront phase maps from a variety of turbulence strengths, particularly where the PWFS response becomes more non-linear. Extensive tests in simulations and in the PULPOS optical bench (3) show that the estimation performance of a modulated traditional PWFS can be achieved by a non-modulated version of the proposed DPWFS. Of course, there is a loss in sensitivity when gaining linearity, similar to what happens with modulation, though this time we can even avoid modulation at all. Somehow, the DPWFS serves to demonstrate that we can offload some of the hurdles of the used linear mathematical inversion process towards an optical preconditioner. Nonetheless, we know that we can achieve even better inversion if we train a deep neural net to solve for the inverse problem related to wavefront reconstruction, as previously reported in (4,5). This is particularly true for a nonlinear system as the PWFS. Therefore, the questions that arises now is whether we can design a DPWFS with a deep optics preconditioner based on a deep neural network for the inversion process, replacing the traditional linear method. In this work we will discuss our current efforts in designing new optical preconditioners for the PWFS based on neural nets. One of the clear caveats of this new adventure is that as we have more free parameters, either in the optical layer or in the digital layers, we may require massive training sets and computational resources. We are currently facing challenges in finding a good balance between the optical and digital layers, though as much as we offload towards the optical side we may expect lightweight computational requirements in the inversion, and thus faster estimations as well. At some point it seems easier to fix as many parameters as possible, which in the DPWFS case is the fixed optical architecture based on the PWFS, though we may also conjecture of what could happen if we remove the pyramid and free the optical transformation of the WFS towards a generalized Deep Optics WFS architecture.

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