Deep learning for low-order phasing of segmented telescopes

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Abstract

Earth observation from space has greatly benefited from advancements in angular resolution, which are essential for obtaining valuable scientific insights. Achieving high angular resolution relies on large telescope apertures. Recently, space telescopes have been designed to exceed the size limitations of the platform and rocket fairing, necessitating segmented pupils. This approach has proven successful for space telescopes (e.g., JWST) but also for large ground-based telescopes (e.g., Keck, ELT). Interestingly, such segmented pupils can also be implemented in small-volume platforms, such as CubeSats, which offer the advantage of reduced payload weight and launch costs, enabling higher revisit rates with satellite constellations.

In our work, we present a novel implementation of a segmented telescope within a CubeSat. While segmented pupils allow for a relatively large aperture, they present a significant challenge in terms of achieving perfect alignment between the independent mirror petals. This alignment is crucial for realising the full angular resolution potential promised by a large aperture. However, the limited computation power and impossibility of having additional optics or dedicated wavefront sensors forces us to perform the wavefront sensing solely on a single focal plane image, requiring the use of more complex methods than classic ones.

One of the main challenges of focal plane wavefront sensing is the non-linear relationship between phase and image intensity. Therefore, we leverage deep learning algorithms to address this problem directly. By utilising the spatial information from each pixel, convolutional neural networks algorithms excel at solving non-linear problems. Moreover, the computational burden is alleviated through off-line training steps, enabling efficient on-board computations.

In this work, we focus on the identification of segmented pupil piston and tip-tilt phase coefficients from a single focal plane image of a point source. Our deep learning-based method successfully extracts the first three Zernike coefficients for each of the four petals,

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even in the presence of noise, higher-order aberrations, and stronger aberrations arising from the initial deployment. We demonstrate diffraction limit results in visible wavelength (about 15nm at 800nm) for relatively small NN architectures compared to the state-of-the-art ones.

We then propose the application of our method to explore the phasing of larger space telescopes with more degrees of freedom, such as JWST with 18 segments. Finally, we extrapolate the potential application of our method to ground-based telescopes.

Keywords: Deep learning, phasing, Wavefront sensing