Focal-plane wavefront control using deep learning for high-contrast imaging

Iremsu Taskin, Jalo Nousiainen, Olivier Absil, Gilles Orban de Xivry, Markus Kasper

1. Introduction

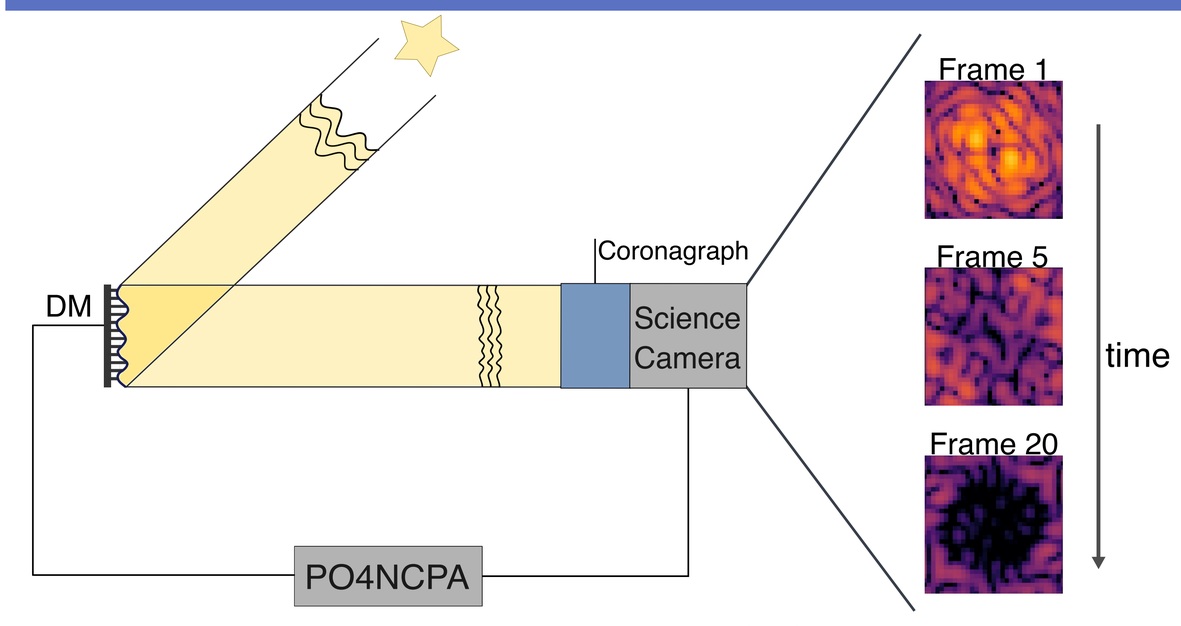

Fig 1.1: The secondary Adaptive Optics (AO) system, fine-tuned to correct NCPAs.

Non-common path aberrations (NCPAs)
- Path difference between science camera & wavefront sensor
- Chromatic aberrations

→ **Focal plane wavefront sensing (FPWFS)**

- Nonlinear relationship between focal plane & pupil plane
- Phase ambiguities

→ **Sequential Phase Diversity + Reinforcement Learning**

2. Reinforcement Learning

PO4AO[2.1] algorithm applied to NCPA: **PO4NCPA**

1. **Running the policy** by controlling DM
2. **Improving the dynamics** model with instrument data
3. **Improving the policy** by using data + dynamics model

Dynamics Model

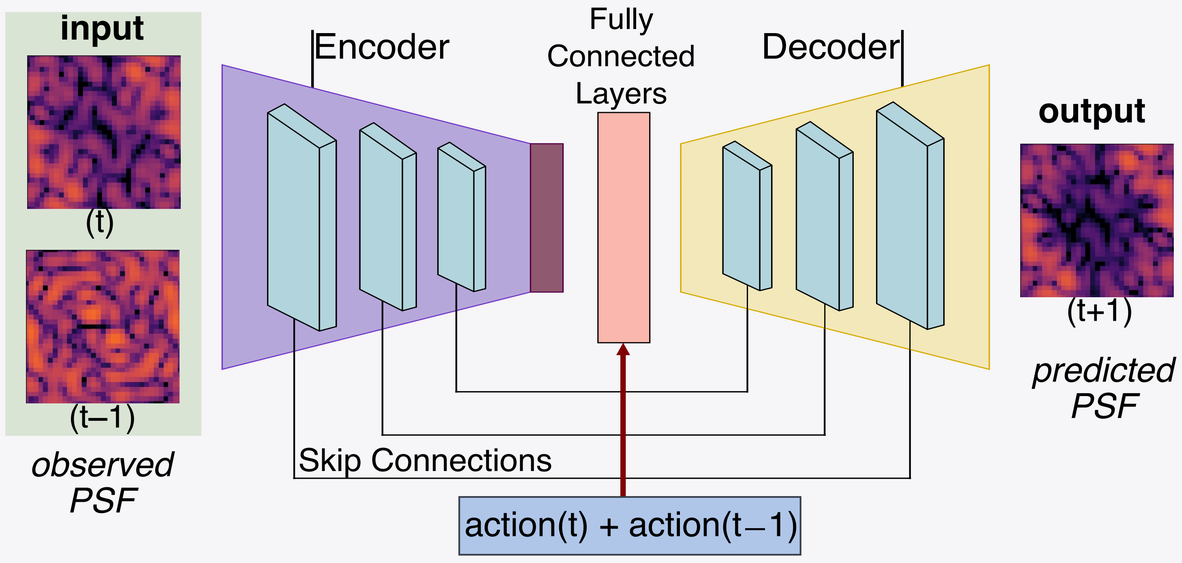

Fig 2.1: The dynamics model takes in the previous and current PSF from the science camera as inputs to predict the next PSF at the science camera. This method uses sequential phase diversity.

Policy

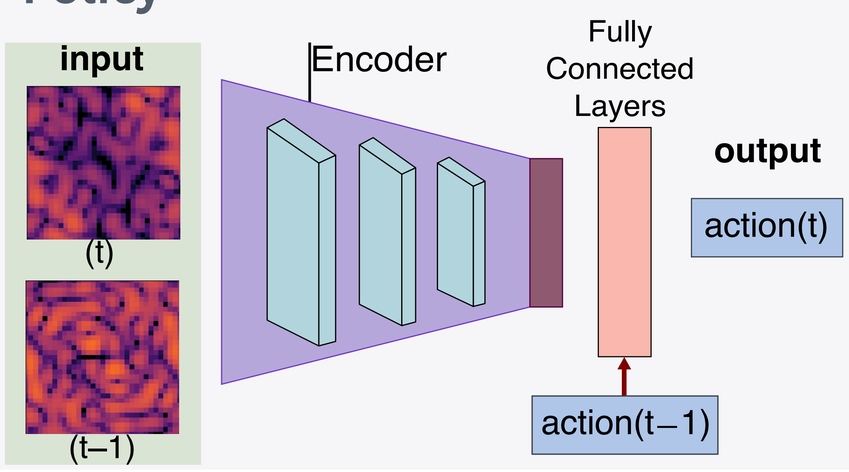

Fig 2.2: The policy uses the current PSF and the previous PSF observed by the science camera to predict the appropriate action.

3. Results

Telescope Diameter	39.3 m
Observation Band	Mid-IR (11 μ m)
# Modes Corrected	55
Frame Rate	10 Hz
Mean NCPA RMS	170 $\pm$ 34 nm

Tab 3.1: PO4NCPA simulation parameters.

Static NCPA: Single frame of aberrations, constant throughout the simulation.
Dynamic NCPA: Water vapor[3.1] effects, evolving throughout the simulation.

Perfect Coronagraph

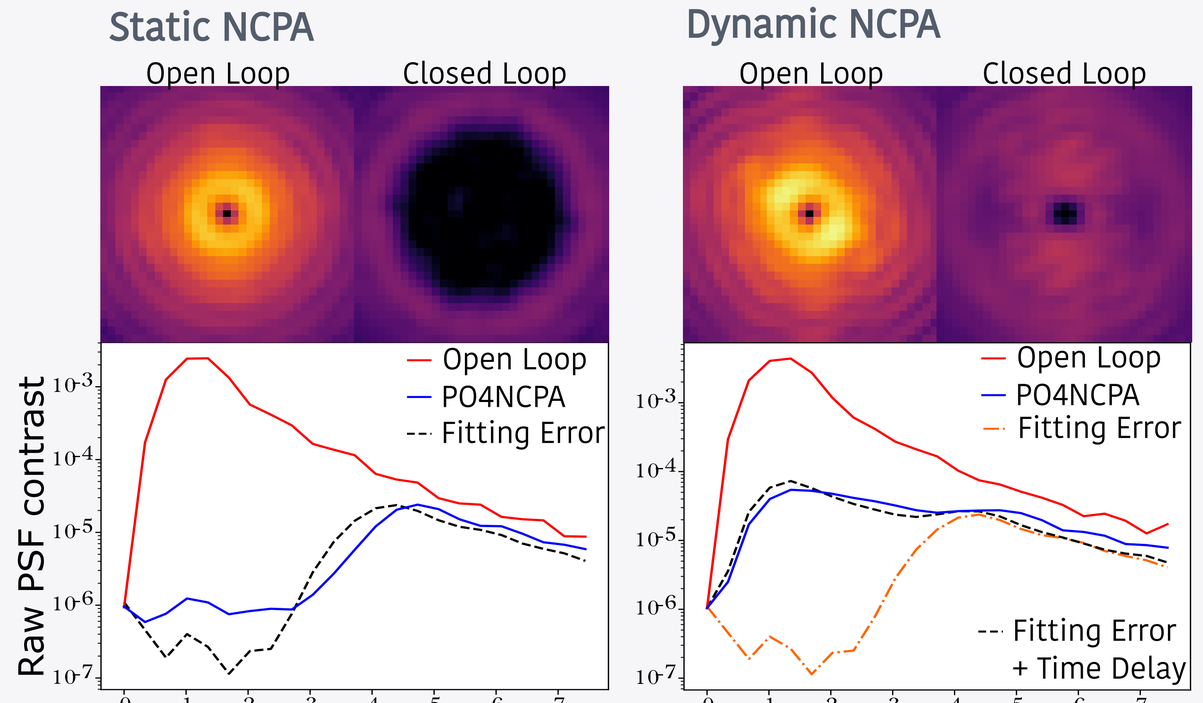

Fig 3.1: The performance of PO4NCPA in static and dynamic turbulence. The curves show the radial profile of the PSF for open and closed loop corrections.

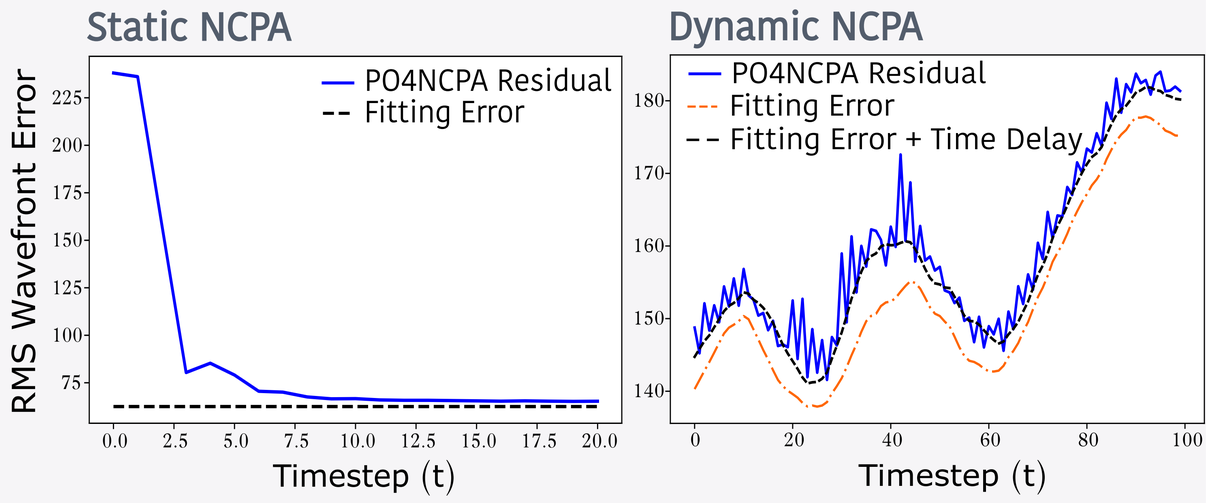

Fig 3.2: Residuals of the static and dynamic NCPA simulations in comparison to the fitting error. PO4NCPA residuals converge to the fitting error early in the simulation for static NCPA. For dynamic NCPA, PO4AO is able to follow what would be expected from a perfect wavefront reconstruction and an integrator.

For videos, please check the QR code.

4. Conclusions

- Model-free
- Correction decision making
- **Can be applied to other types of imaging** (scalar/vector vortex coronagraph, normal imaging) & instruments
- Next step: **Dark-hole digging**
- Future on-sky testing with SCEXAO instrument, Subaru

[2.1] Nousiainen, J., "Toward on-sky adaptive optics control using reinforcement learning. Model-based policy optimization for adaptive optics", Astronomy and Astrophysics, vol. 664, Art. no. A71, EDP, 2022. doi:10.1051/0004-6361/202243311.
[3.1] Absil, O., "Impact of water vapor seeing on mid-infrared high-contrast imaging at ELT scale", Adaptive Optics Systems VIII, 2022, vol. 12185, Art. no. 1218511. doi:10.1117/12.2627972.