Focal Plane Wavefront Sensing on SUBARU/SCExAO


Subaru telescope, Leiden observatory, University of Sidney, Observatoire de la Cote d’Azur, ONERA, Caltech, Univ. of Toronto

Context: Instrumental limitations to High Contrast Imager performance

➢ The Island Effect
  Fragmentation of the pupil
  ➢ Differential piston effect, segmentation...

➢ Low Wind Effect
  ➢ A thermal effect (see Fig. on the right):
    - The temperature differential between ambient air and spider induces radiative exchanges that create refractive index gradient near spiders when the wind speed is low (typically < 3m.s⁻¹)

➢ Sources of aberrations which limit the achievable contrast or resolution of high contrast imagers

➢ The Non-Common Path Aberrations
  Wavefront sensor light path differs from science light path
  ➢ Aberrations in the science path are not corrected by the wavefront sensor

Zernike Asymmetric Pupil (ZAP)

➢ Principle
  ➢ Phase retrieval with asymmetric pupil mask

➢ Hardware requirements
  ➢ Asymmetric pupil mask
  ➢ Focal plane image

➢ Latest results
  ➢ On-sky loop closure : 37% gain in Strehl

Linearized Analytic Phase Diversity (LAPD)

➢ Principle
  ➢ Linearized phase diversity with extended capture range
  ➢ S. Vievard et al., 2020

➢ Hardware requirements
  ➢ Focal plane image
  ➢ Defocused image

➢ Latest results
  ➢ Lab loop closure

PSF reconstruction using Neural Network

➢ Principle
  ➢ Train deep neural network with synchronized Pyramid Wavefront Sensor telemetry and focal plane image
  ➢ Real-time PSF prediction using the PyWFS telemetry

➢ Hardware requirements
  ➢ Pyramid Wavefront Sensor telemetry
  ➢ Focal plane image

➢ Latest results
  ➢ On-sky
  ➢ - PSF prediction from Pyramid telemetry

Single image Phase Diversity

➢ Principle
  ➢ Assumption of point source and large defocus : apply PD to one image

➢ Hardware requirements
  ➢ Defocused image

➢ Latest results
  ➢ Lab open-loop estimation (M. Lamb)

DR WHO

➢ Principle
  ➢ Direct Reinforcement Wavefront Heuristic Optimization (DR WHO), updating PyWFS reference using lucky imaging.

➢ Hardware requirements
  ➢ Pyramid Wavefront sensor
  ➢ Focal plane image

➢ Latest results
  ➢ Simulation: Gain of 8% in SR

Conclusion and perspectives

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>ZAP</th>
<th>vAPP PR</th>
<th>LAPD</th>
<th>Fast and Furious</th>
<th>Single image PD</th>
<th>Neural network</th>
<th>DR WHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>Pupil mask</td>
<td>Focal plane</td>
<td>Focal plane</td>
<td>Focal plane</td>
<td>Defocused plane</td>
<td>PyWFS image</td>
<td>PyWFS Focal plane</td>
</tr>
<tr>
<td>Simulation</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>In progress…</td>
</tr>
<tr>
<td>On-bench</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>In progress…</td>
</tr>
<tr>
<td>On-sky</td>
<td>✓</td>
<td>✓</td>
<td>In progress…</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>To do…</td>
</tr>
</tbody>
</table>

➢ Multiple options available to increase the wavefront quality, depending on the observing mode

➢ SCExAO: key platform to test and validate new concepts/algorithms

➢ Key for future challenges on Extremely Large Telescopes