National Aeronautics and Space Administration

Hybrid Wavefront Sensor for Daytime Optical Communication

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Strategic Focus Area: RF and Optical Communications

Objectives

We are building a new type of wavefront sensor (WFS) that combines the best features of the two most popular WFS types.

- The Pyramid WFS is able to observe very faint signals
- The Shack-Hartmann WFS can operate in highly turbulent conditions.

The Hybrid WFS integrates elements of both with no moving parts and is able to synthesize an optimal correction signal from the two modes simultaneously. Our objectives during this project were to

1. Build a tool to model performance,
2. Create a laboratory prototype of the system and then
3. Validate the model against the prototype

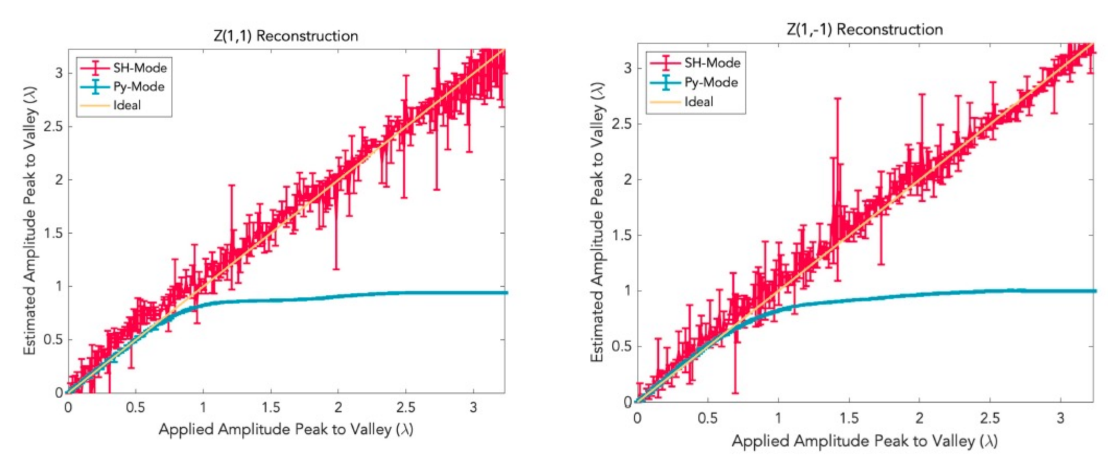

Figure 2 The first aberration we applied was tip and tilt using the fast steering mirror. The SH-Mode remains accurate over the full range, but shows a less consistent estimation. The Py-Mode saturates around 1λ, but shows a significantly more consistent response.

This is exactly what we expected after the simulations done last year

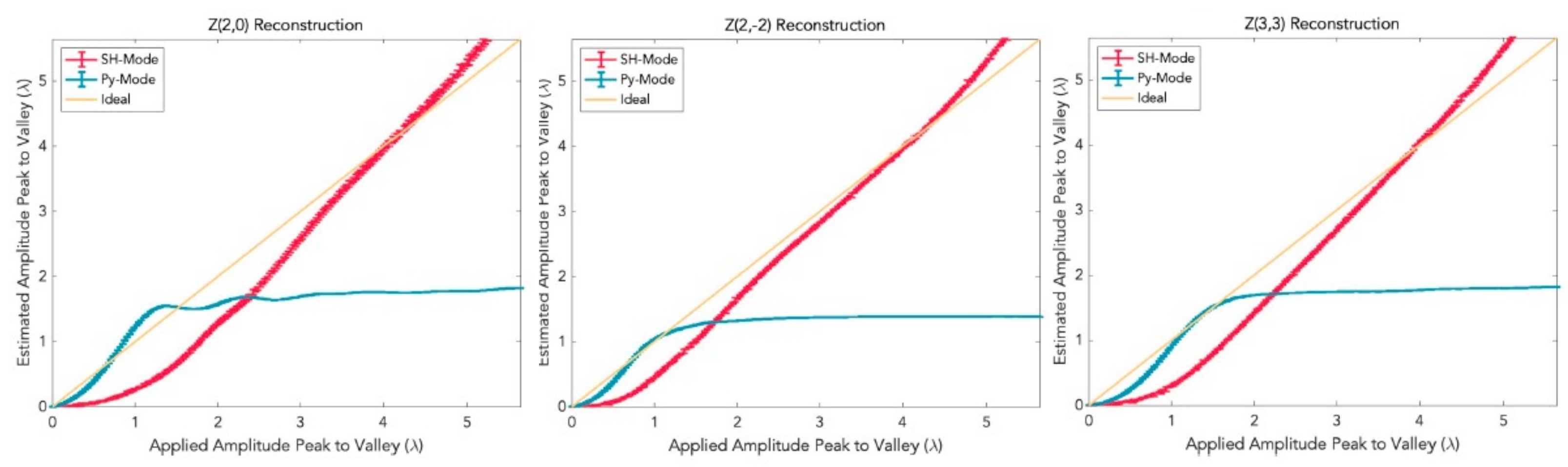

Figure 4 Results from tests of the HyWFS using the DM to apply aberrations. These graphs show the results from defocus (top), astigmatism (center), and trefoil (bottom). No linearity correction was applied. That would require an interferometer to calibrate out the non-linearity and that was insufficient time for that.

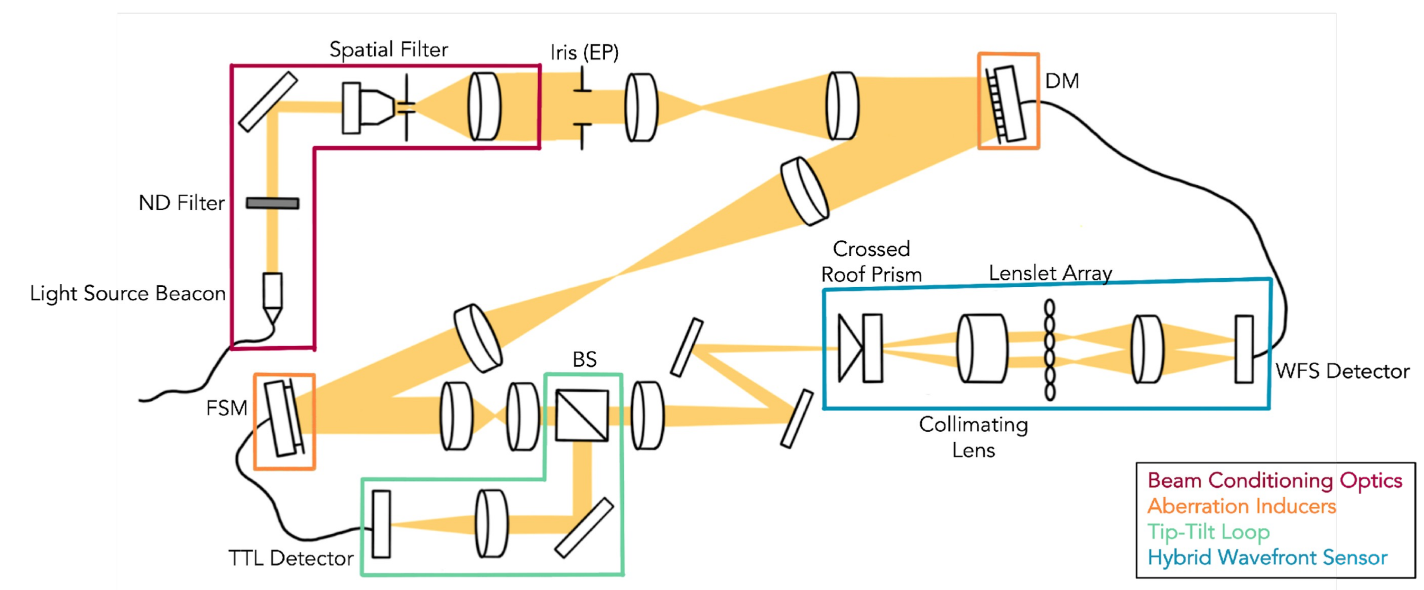

Figure 1 A schematic of the layout of the testbed. The major components are labeled. DM: Deformable Mirror, ND: Neutral Density, FSM: Fast Steering Mirror, TTL: Tip/Tilt Loop, BS: Beam Splitter, WFS: Wavefront Sensor

In 2022, we finished the alignment and calibration of the hardware. The next step was to test out how well the wavefront sensor can sense individual Zernike modes.

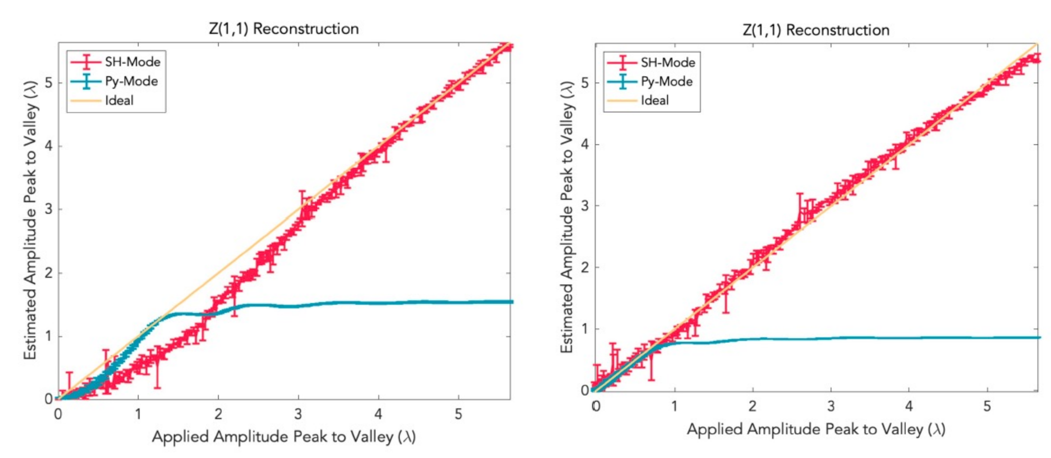

Figure 3 After applying tip/tilt using the FSM, we applied it using the deformable mirror (DM). In an ideal world, these would be identical to the FSM results. Instead on the left figure, we see both SH-WFS and Py-WFS differ from the ideal case. This is from the nonlinear performance of the DM. The figure on the right shows the WFS response when corrected for the DM non-linearity. This makes for a distinct improvement and the overall performance is close to the ideal performance.

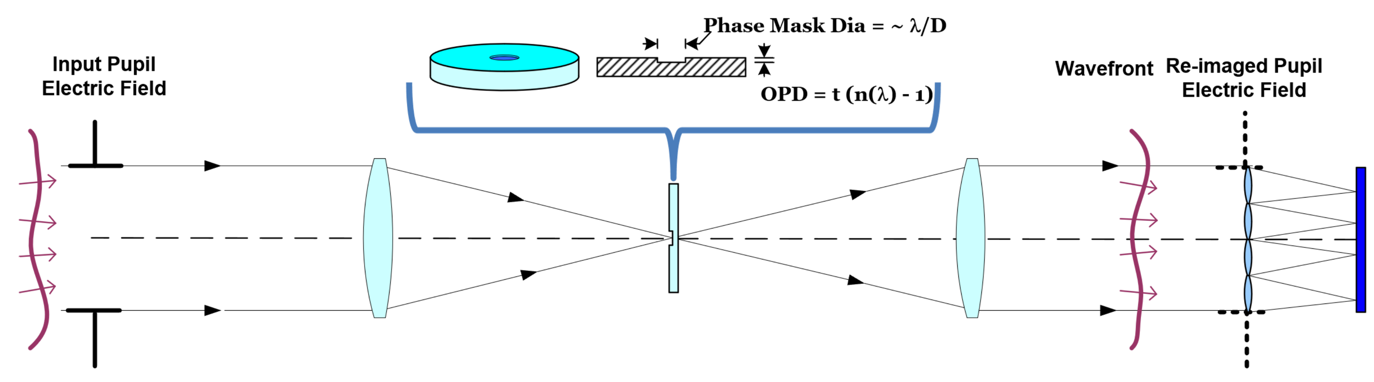

Figure 5 We are also studying the hybridization of a Shack-Hartmann and a Zernike sensor. The Shack-Hartmann has the benefit of large dynamic range, while the Zernike has the benefit of unmatched sensitivity. This alone would be a great advantage. However, it's also the case that the hybridization can be done is done is a very straightforward way – both opto/mechanically and with the reconstruction.

The benefit of this architecture is that the Zernike mask does not impact the location of the centroids in the Shack-Hartmann sensor. The same centroid calculation holds. However, in closed loop, as the correction gets better and better, and the PSD at the location of the Zernike phase mask is sharpened, the intensity per each lenslet subaperture corresponds to the phase of the wavefront at that sub-aperture. The phase reconstruction is then just the intensity of the light at that subaperture (properly normalized by the total light in the pupil). This reduces the dimensionality of the reconstruction by a factor of two.

We have initiated some simulations to demonstrate the benefit of this method, but there is still work to be done to mature the complete simulation.

Significance/Benefits to JPL and NASA

There are two main NASA uses of Adaptive Optics:

1. Optical communication ground stations such as Laser Communication Relay Demonstration (LCRD)
2. Extreme Precision Radial Velocity measurements of exoplanets around host stars.

These wavefront sensors may also be useful in active optics systems for space telescopes, where we are correcting slowly changing aberrations in the optical system.

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Publications:

C.E. Guthery 2022, "A Hybrid Wavefront Sensor for Wide-range Adaptive Optics", Ph.D. Dissertation University of Arizona

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