National Aeronautics and Space Administration

Hybrid Wavefront Sensor for Daytime Optical Communication

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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.

This is illustrated in Figure 1. 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.

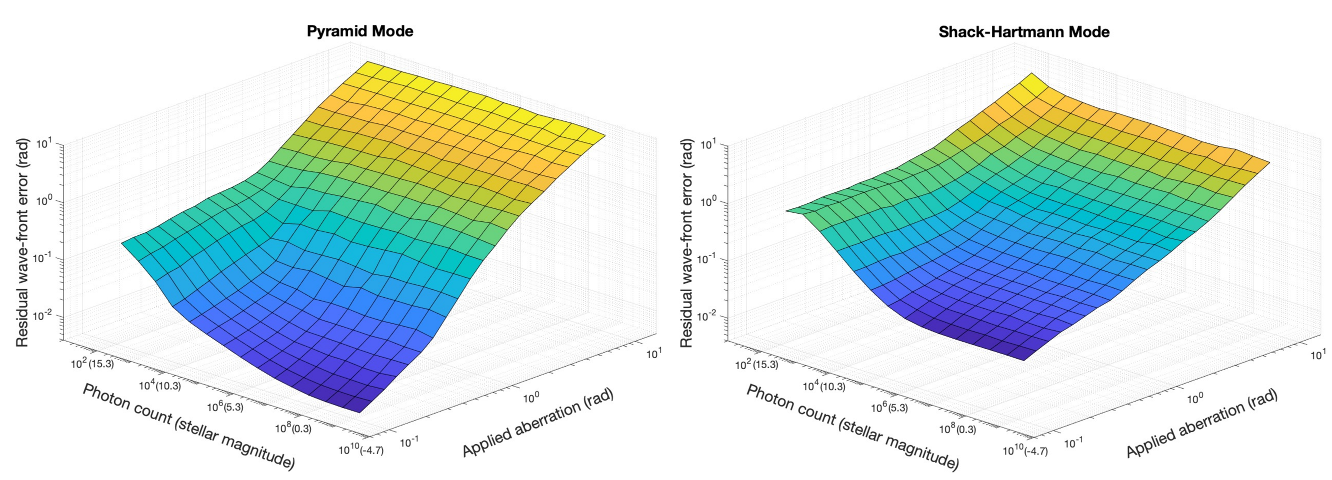

Figure 1. Residual wave-front error as a function of photon count and aberration strength. On the left is the result from the PWFS reconstruction method. On the right is the result from the SHWFS reconstruction method. This shows the various regimes where one technique is better than the other.

Background

For coherent optical communication systems such as Laser Communication Relay Demonstration (LCRD), AO is key to coupling sufficient light into the modem's single mode fiber (Roberts et al. 2018.)

It can also increase the data rate for deep space optical communication during the day by as much as 30-50 times (Roberts et al. 2019.) The heart of any AO system is the wavefront sensor, which measures the aberrations in the incoming light and sends commands to the deformable mirror (DM) that corrects those aberrations.

Being able to observe fainter signals increases communication link margin and enables the ground station to handle small amounts of clouds. A ground station with a Hybrid WFS fed AO system will have increased ability to operate through clouds and turbulence conditions. This means that a communication network will require fewer ground stations with potentially significant cost savings.

This technology can also be used to improve the performance of AO systems searching for exoplanets, including extreme precision radial velocity (EPRV) surveys. Improved performance on fainter stars will yield shorter exposure times and increased science yield.

Approach and Results

The University of Arizona had previously created a model of the Hybrid WFS. The main part of this project is to create a laboratory prototype of the system and then validate the model against the prototype.

The testbed was first designed in optical ray trace software. A block diagram of the system is shown in Figure 2. Over the last year, the testbed has been assembled and tested. The latest version of the testbed is shown in Figure 3. As expected with any testbed, there are have been numerous issues uncovered through testing and analysis of the results. These issues have been addressed and testing continues.

When we are comfortable with the performance of the system, we will move to validate the model with data from the testbed. A partial version of some of the comparison between modeled and measured data is shown in Figure 4. This will then enable the model to be used to design operational systems.

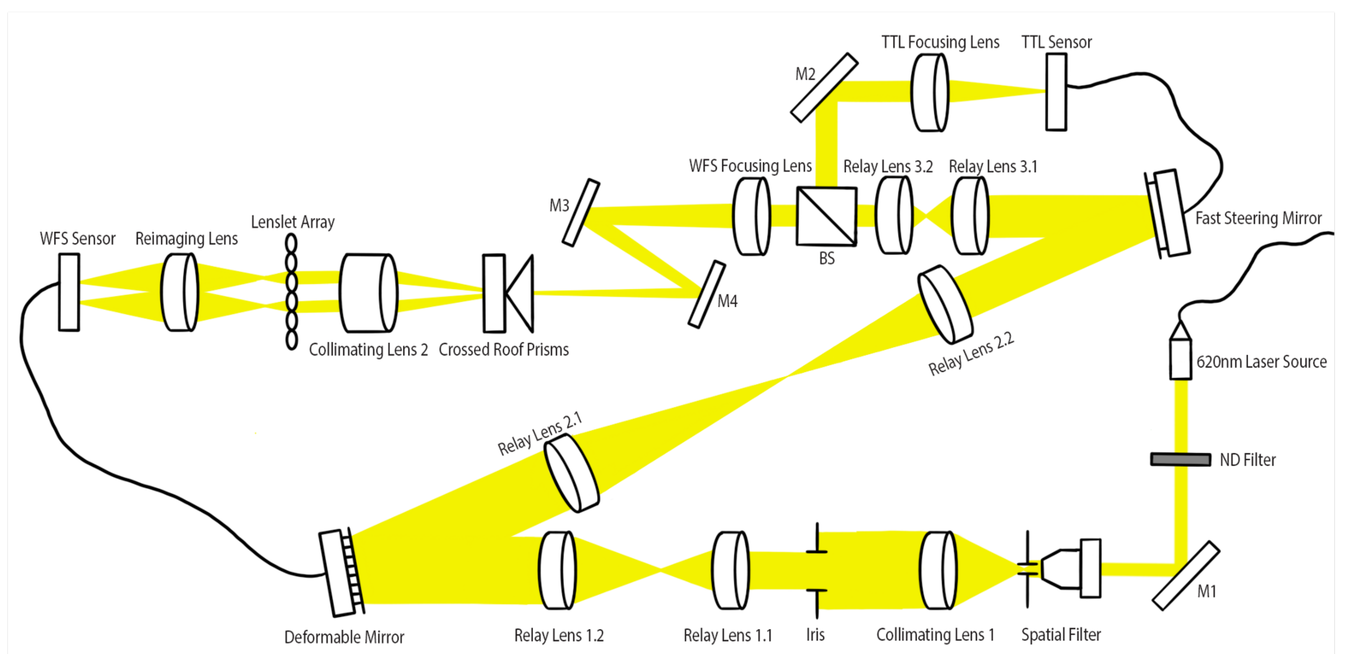

Figure 2. An optical block diagram of the testbed. The light path starts at the 620nm light source on the right and goes to the WFS Sensor on the left. Figure 2 shows the assembled testbed.

Significance/Benefits to JPL and NASA.

There are two main uses of AO for NASA missions.

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

We believe that the hybrid WFS has the potential to improve both of those missions. In Year 2 of this project, we study the benefits for each mission.

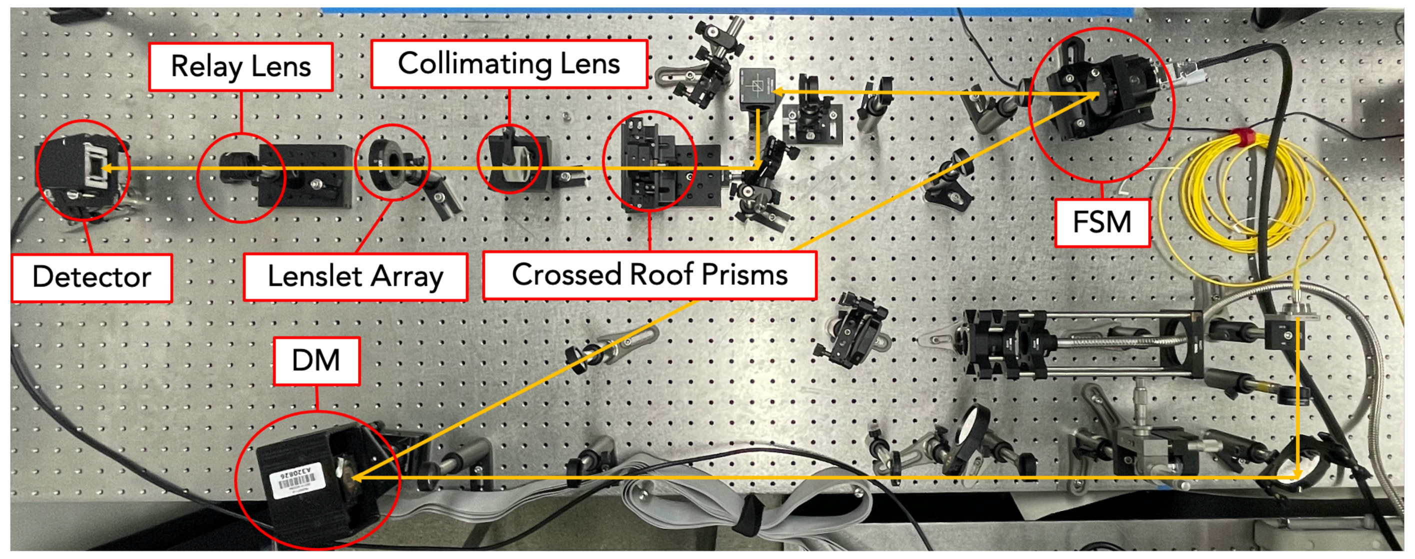

Figure 3. A photograph of the testbed. The major components are labeled. The orange line shows the light path from the fiber light source on the right to the detector on the left.

Publications

Guthery, C & Hart, M. *Pyramid and Shack-Hartmann hybrid wave-front sensor,* Opt. Letters, 46, 1045 (2021)

Jean, M., Knight, J., Guthery, C., Hart, M., & Kim, D. *Design and calibration of a closed loop tip-tilt control for a pyramid-Shack-Hartmann hybrid wave-front sensor*, Proc. SPIE, 11836, pp118360A (2021)

References

Roberts Jr., L.C., Meeker, S.R., Piazzolla, S., & Shelton, J.C., *Daytime Adaptive Optics for Deep Space Optical Communication*, Proc. SPIE, 11133, 1113308 (2019)

Roberts Jr., L.C., et al., *First results from the adaptive optics system from LCRD's Optical Ground Station One*, Proc. AMOS Conference (2018)

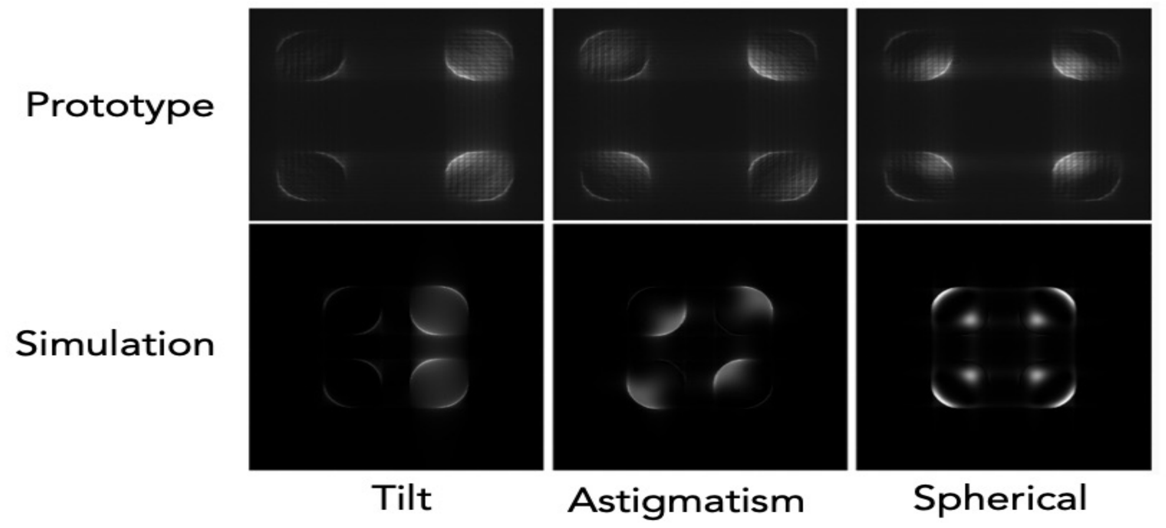

Figure 4. The modeled response to various aberrations and the measured response from the Pyramid WFS. The two show a similar response in that astigmatism shows that saddle-like shape and spherical is radially symmetric. Most of the differences are because the scale of the aberrations is not the same. The simulations apply a somewhat arbitrary phase to the system, while the bench is using the DM at ~75% stroke. Still the general agreement leads us to believe that the prototype is generally working as expected.

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