Scene-based Wavefront Sensor

Technology Need and Application Domain

Imaging systems are frequently deployed on either airborne or orbiting platforms to gather intelligence about selected scenes. The image resolution and the signal to noise ratio (SNR) of these imaging systems improve as the size of the entrance aperture is increased. One cost effective means of creating a large aperture is using a segmented primary mirror which can be transported in segments and assembled to create a large mirror upon arrival at the platform. The problem is that a segmented primary mirror will induce image degrading aberrations (segment pistons and tilts) as the segments move with respect to each other due to vibrations induced by platform motion (slew) and operation of system components, such as gyros, coolers, etc. Furthermore, thermal loading can cause deformation of the segments resulting in higher order aberrations, along with other degrading effects such as manufacturing imperfections and contamination. Satisfactory performance requires that these aberrations be corrected using a suitable adaptive optics system.

Conventional adaptive optics techniques fall short for this application since they have been designed to correct aberrations using sensors that measure the wavefront of laser light that samples the aberrations throughout the system. It is very difficult to provide such error signals for an airborne imaging system. Either the laser source would have to located in the scene or on-board the platform. The first is not feasible since scenes that are being imaged are usually not cooperative. The second requires many interlocking laser beams to form a complex and expensive optical truss.

A simpler solution is to use the light from the scene that propagates to the imaging system and interrogates all of the optical surfaces within the system. Development of such an adaptive optics system that uses the actual scene as the measurement source would enable correction for all of the aberration degrading disturbances from the primary mirror to the imaging focal plane array (FPA) in one simple measurement.

Technology Highlights and Status

Optical Physics Company (OPC) completed the design, manufacture and test of a scene based wavefront sensor for the application domain described above. The overall system block diagram is shown below in Figure 1.

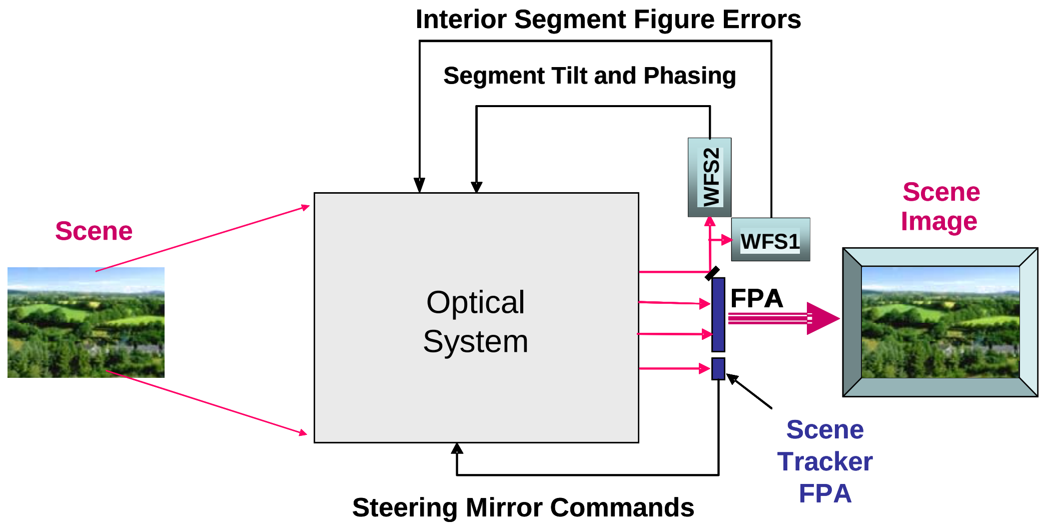

Figure 1. Overall system block diagram showing the control processes towards corrections for tracking, high-order (interior segment figure), segment tilt and segment phasing wavefront aberrations.

The system performs multiple functions:

1. Segment tilt correction
2. Segment phasing correction
3. High order (interior segment figure) error correction
4. Scene tracking

The first two functions are specific to segmented optics whereas the last two apply to both segmented and unsegmented optics.

Two wavefront sensors, labeled (WFS1) and (WFS2) are the key elements of the system.

WFS1 provides high order (interior segment figure) error measurements. High order aberrations arise primarily from disturbances such as atmospheric turbulence, static manufacturing aberrations on the optical surfaces, contamination on the optical surfaces, and thermal distortions of optical surfaces. The control process is essentially the same for optical systems with and without segmented optics.

WFS2 is at the heart of the innovation. Its function is to provide intra-segment tilt and inter-segment phase wavefront errors to the optical system. These errors, as their descriptions suggest, are specific to segmented optics. Tilts arise from the orientation of the individual segment. They need to be measured per segment, whereas phase differences occur between segments.

The photo of the final product is shown on the left in Figure 2.

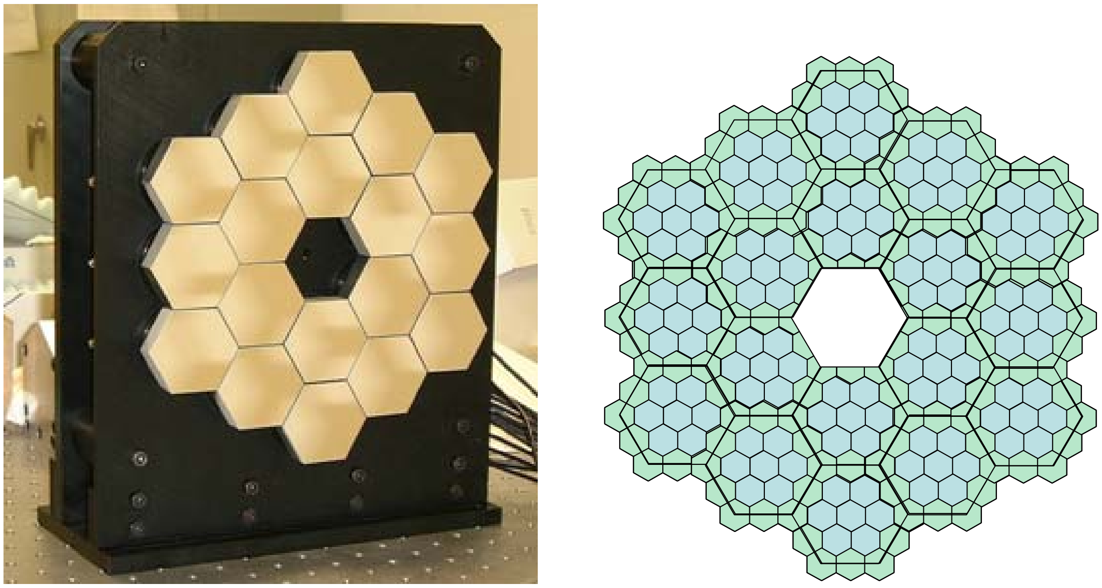

Figure 2. ***OPC's scene based wavefront sensor. The segmented primary mirror (also fabricated by OPC) is shown on the left. The surface is optically coupled to two types of subapertures with position sensitive detectors. One type is shown in blue and the other in green overlayed with the corresponding reflecting surface segments.***

The key innovation, WFS2, has two types of subapertures that are coupled to the segmented reflective surface as shown on the right side of Figure 2. Each subaperture is defined by a lenslet conjugate to the primary mirror. Lenslets from each subaperture image the scene onto a focal plane array (FPA). One type of subaperture (shown in blue) receives light from a single reflective surface segment and measures tip/tilt errors of the interior wavefront aberration. The other type (shown in green) receives light from the abutting edges of adjacent reflective segments and measures phasing errors between segments. The combination of both types of data permits complete rigid body correction of all segments.

The scene based wavefront sensor has one detector array per subaperture (typically 32x32 pixels). Each detector array is positioned at a focal plane of its corresponding subaperture to receive light from that subaperture only.

A complete turn-key system was delivered in 2005, and received a Silver Supplier Award.