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Technical Note on a Proposed Wavefront Sensing Field Scan and Relay Optic Concept

Jim Oschmann
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Introduction

The following describes a possible field scanning and associated relay optic concept for use with the facility adaptive optics wavefront sensor (AO FWFS) and a slight variation of which may be used in some instruments for support of the on instrument wavefront sensors (OIWFS). Conjugation of the deformable mirror (DM) to altitude adds some complexity to the AO system. With conjugation to altitude, the DM must be oversized (compared to conjugation at the pupil) so that some of the light from off axis guide stars are not vignetted by the edge of the mirror. This is of particular importance when using the AO system in the near IR where one wishes to minimize thermal background. With this arrangement, the footprint of an off axis guide star on the DM is off set from the footprint of an on axis point (center of science field). Some systems proposed require that the DM and/or the AO FWFS move to keep everything centered on the guide star (to sense and correct the guide star path completely). The key advantage of the concept proposed here for AO use is it can be used with the deformable mirror (DM) in one location relative to the science path for guiding at any point in the field of view and during nodding operations. This results in no changing background effects being introduced by this system as seen by the infrared scientific instrumentation.

The basic idea for this concept was adapted from a UKAO design presented to Gemini at a fall of ‘95 A&G/AO science working group meeting, by Richard Myers. The UKAO concept for conjugation to altitude and associated field scanning method was developed by Martin Wells of ROE and was slightly modified here to eliminate a field lens and to expand the concept to an oversized lenslet and CCD for the Shack Hartmann sensor by the author.

The concept described here consists of a system with the following:

DM conjugate to 6.5 KM altitude (above site)
Fixed DM and WFS pickoff beamsplitter (dichroic)
Collimator covering 2-3 arcmin diameter guide field
Gimbal style field scan mirror, conjugate to the DM
Relay optics after scan mirror designed for near zero field with aperture at focal plane
Lenslet array for SH example, conjugate to gimbal mirror (and fixed)
Lenslet array and CCD detector are oversized

For OIWFS use in instruments, it uses a gimbaled field scan mirror (at a telescope pupil conjugate) with a fixed wavefront sensor head. This may be highly desirable where the OIWFS needs to be placed within a cold dewar and cannot afford to have wires and cables moving large distances (to avoid breakage!). Only a small change of spacing is required for the AO concept to conjugate to the telescope pupil (desirable for tilt and focus correction). To summarize the system here:

Changeable dichroic splitter to separate science and WFS light (for near IR instruments)
Collimator covering > 3 arcmin diameter guide field
Gimbal field scan mirror conjugate to telescope pupil
Relay optics after scan mirror designed for near zero field with aperture at focal plane

Lenslet conjugate to gimbal mirror

This system is not compatible with pickoff schemes which "search" the focal plane as envisioned for GMOS at this time (and is not proposed for such instruments!).

This concept was first discussed for use on Gemini at the last AO/A&G science working group and borrows from a similar concept proposed for the UKAO program.

Optical System Description

To illustrate the concept, a first order layout is shown in Figure 1. It is shown as an unfolded transmissive system for simplicity of explaining the concept. The assumptions are:

- Deformable mirror is located at altitude conjugate of 6.5

- DM remains fixed (does not move with guide field position) and centered on the optical axis

- DM is oversized so that it does not vignette an off axis guide star at up to 1-1.5 arcminutes

- For this illustration, the science beam is reflected from a pick off beamsplitter located at a positive focus produced by a lens after the DM and telescope pupil. This is not the same as the current optical design, but the same overall concept could be implemented with this too

- This illustration just keeps it simpler. A suggestion has been discussed briefly which may modify the optical design to be more consistent with the concept shown here, but that is to be considered independently. The pick off for the science path is shown as a 45 degree tilted element, but no optics downstream are shown in Figure 1.

- The only moving element in this design is the gimbal mounted mirror which is depicted by folding the beam in Figure 1, which is after the beamsplitter pickoff for the science path.

- The final image relay is consistent with a Shack-Hartmann type wavefront sensor for illustration purposes due to familiarity of the author. Other wavefront sensor types could be inserted here, probably resulting in changes in the final relay design. The scanning method still applies.

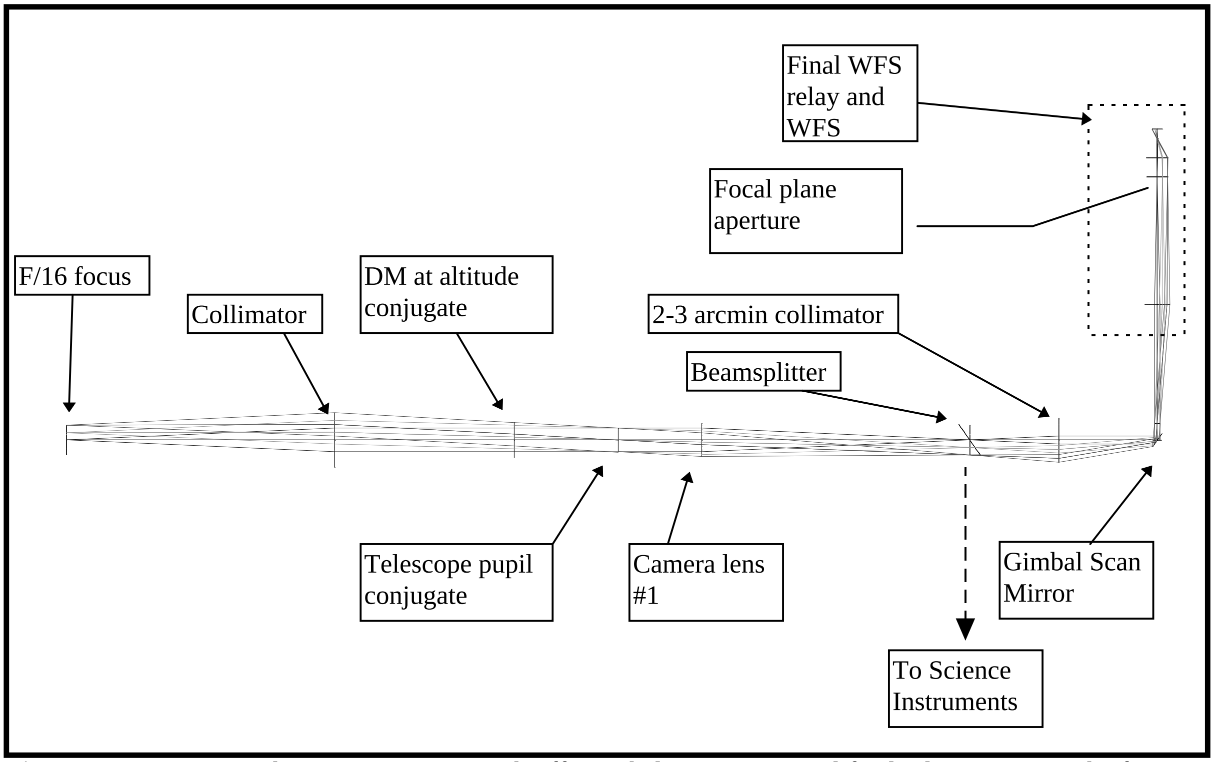

Figure 1. AO FWFS with AO optics, WFS pick-off, gimbal scan mirror and final relay concept. The figure is note quite scale, but the distance from the first focus to the gimbal scan mirror is 3.9 meters and another 780 mm to the WFS ccd (in this example).

In the concept shown in Figure 1. the collimator provides a 60 mm diameter beam on the DM. The DM is oversized for a 2-3 arcminute diameter field. For this example, a 2 arcminute diameter field is used. The DM is located at a 6.5 KM conjugate plane. Figure 2 shows beam footprints for an on axis point source, 0.5 arcminutes, and 1 arcminute off axis. The overlap of these region shows how much of the on axis science beam is directly measurable and correctable from various off axis guide stars. The non-overlap region (of the science path) could either be "flattened" or controlled to a desired extrapolated shape. The outer region of the DM is simply held flat with an outer set of guard ring actuators if a SAM or follows the reactive natural mirror modes if a bimorph designed for control over the central region.

A fast tip/tilt mirror could be located at the plane conjugate to the telescope pupil in this arrangement (see figure 1 above). Following the telescope pupil conjugate, a positive powered element would be used as the first element of a pupil relay telescope for the wavefront sensor path and a first element of a beam shaping telescope (or camera) for the science path (to provide a beam exiting the AO subsystem at f/16 and a focus coincident with the nominal telescope focus, without AO). In the current design, this is a negative powered mirror. For our current optical design, the beamsplitter which separates the science and WFS path is after a final positive powered mirror. This example moves the beamsplitter in front of this final powered element. The same overall concept will work for either case.

As mentioned, next in the layout is the beamsplitter (dichroic) for separation of the science and WFS path. which is located at an intermediate focal plane in this example. After the beamsplitter, a collimator is used as a final element of the first WFS relay telescope. This collimator is a bit more complex than most of the optics involved in previous WFS pick-off schemes as it must cover the entire guide field desired (2-3 arcminutes). It will likely have to be a 2-3 element design, somewhat larger than the optics which follow. For use in instruments such as the 1-5 micron imager, it may simply be a ‘copy’ of the IR science path collimator, simplified for a smaller bandpass.

Following this collimator, there is another conjugate plane to 6.5 KM (and the DM) at which a gimbaled field scan mirror is located. The beam size in this location is 20 mm, but this can easily be changed. One thing to avoid here is making the beam size at this conjugate plane too small. The smaller the beam size here, the closer the image planes of the DM and the telescope pupil become and the more critical the placement of the gimbaled mirror!

The beam foot prints of interest on the gimbal mirror are shown in Figure 3.

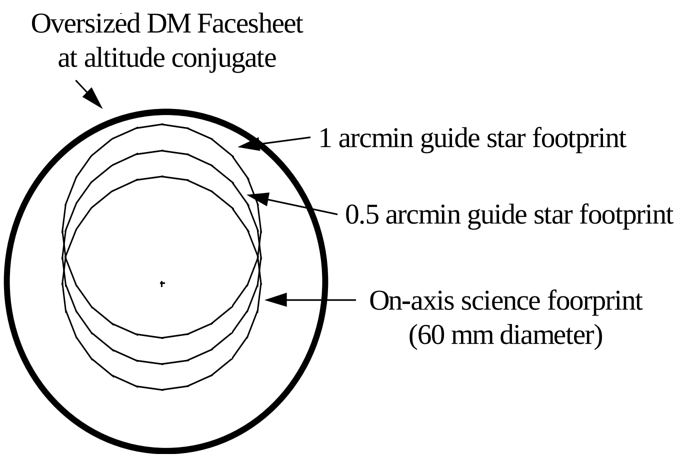

Figure 2. Foot print versus field position on deformable mirror.

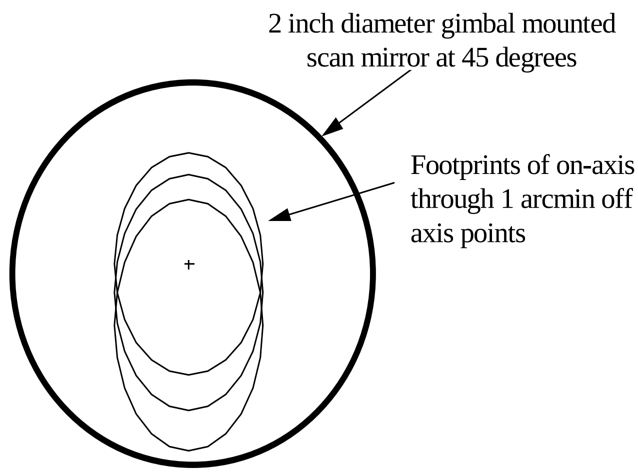

Figure 3. Beam footprint at gimbal scan mirror.

Following this gimbal mirror, all optics can be designed for essentially zero field (other than for alignment tolerance considerations) and do not move. The final relay optics consist of another telecentric telescope with an aperture stop at the intermediate focus. For this SH example, the telescope relays the altitude conjugate plane (from the gimbal mirror location) to the lenslet array location, at a size of 3 mm. This may be changed, especially as required for other wavefront sensors. As was the case for the DM and gimbal mirror location, the beam footprints of interest are the same (rescaled by the relay telescope magnification). Each ‘footprint’ is 3 mm in diameter, with the off axis ones vignetted compared to the on axis case. This is shown in Figure 4.

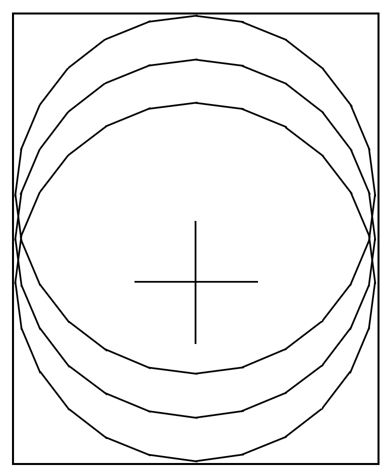

Figure 4. Beam foot print on axis versus off axis guide star at 3 mm lenslet array location. Though example may be typical of a SH design, principle is similar for other wavefront sensors.

Now in practice, light from off axis sources should be filtered out. This is accomplished with an aperture placed at the intermediate focus of this final relay telescope. It is fixed (may be ‘opened’ or removed for acquisition) to reject any light other than that which is entering this final relay telescope parallel to the optical axis (with an aperture in the 1-3 arc sec range). The gimbal mirror is used to direct light from the desired off axis or on axis guide star through this aperture. This is illustrated in Figure 5.

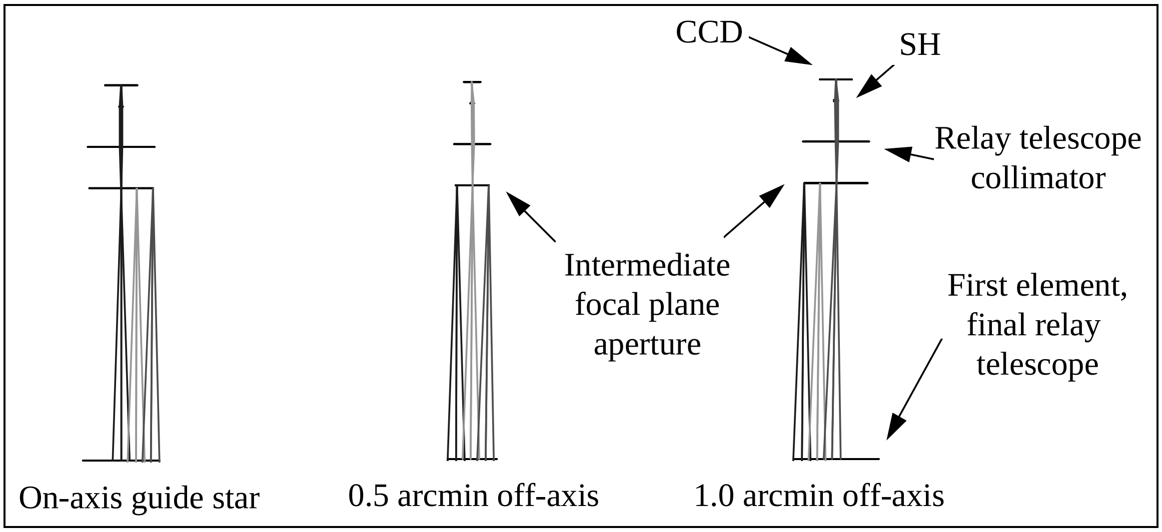

Figure 5. Effect of gimbal mirror selecting which off axis point to pass through aperture at focus. Gimbal mirror not shown.

Even though the gimbal mirror selects which off axis point passes through this aperture in the relay telescope, the relayed pupil (relayed from gimbal mirror to lenslet array location) is offset for a given off axis point. This is shown in Figure 6. The 1 arcminute point is shown at the lenslet array location (other points filtered out). The cross in the center shows the center of the lenslet array. A rough outline of a 6x6 SH lenslet array is shown (was too tired to draw an 8x8 or larger!).

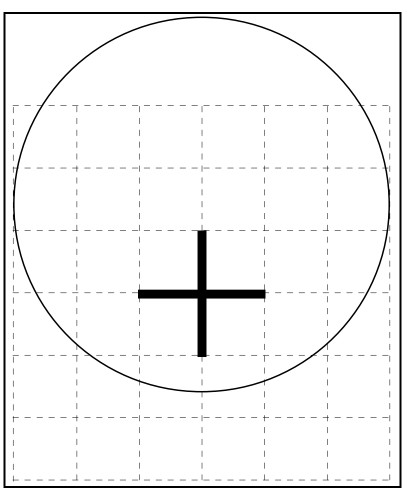

Figure 6. Lenslet array and off axis pupil.

As shown, the 1 arcminute off axis point vignettes the lenslet. The light focused by these lenslets still falls on the same location on the CCD since the gimbal mirror directed this light to fall in the center of the aperture defined previously. By oversizing the lenslet array (adding more lenslets to cover a larger than 3mm diameter pupil), and oversizing the CCD (for a SH case), the entire wavefront produced by the off axis source is measured without having to move the lenslet or CCD! An oversized lenslet and CCD are not a cost driver - the CCD is already oversized for the resolutions considered!

The last part of this method (lenslet array oversized and CCD) are unique to the SH design. Other WFS’s may or may not be able to use similar ‘tricks’ to reproduce the entire measured wavefront without moving parts. The lenslet remains fixed relative to the DM only because it is at a conjugate of the DM and the gimbal field scan mirror. For the AO system, this allows the DM to remain fixed. The IR instruments see no varying background from moving components since no moving components exist in the science path.

For use as a field scan and relay system for on instrument wavefront sensors, small changes in spacing (location) of the gimbal mirror and the final lenslet array would be required. Both would be placed at a conjugate of the telescope pupil instead of a conjugate of 6.5 KM. This would eliminate any pupil 'wander' as further off-axis guide stars are used. For this example with these intermediate pupil sizes, the gimbal mirror would move about 41 mm further from the large WFS collimating optic to place it at a telescope pupil conjugate (and correspondingly closer to the final WFS relay telescope) and the SH lenslet and CCD would move less than 1 mm further away. For use inside of cooled instruments such as the 1-5 micron imager, this may be an attractive consideration since it virtually eliminates the need for cabling to travel any distance within the cold dewar (one gimbal axis motor will probably have to move slightly). The drawback is that the first collimator after the WFS pick off dichroic is larger than and possibly has more elements than other field scanning methods considered.