Opto-mechanical Registration Tolerances for "go-to" Adaptive Optics

KECK ADAPTIVE OPTICS NOTE 704

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December 2, 2009

ABSTRACT

This note considers the tolerance for lenslet to deformable mirror registration for a pure "go-to" adaptive optics system. Comparisons are made to the NGAO wavefront error budget and tolerances for registration in conventional closed loop adaptive optic systems. It is found that the tolerance is comparable in "go-to" and conventional AO systems.

Revision History

Revision	Date	Author (s)	Reason for revision / remarks
1.0	December 2, 2009	C. Neyman	Initial release

1. Introduction

One advantage for "go-to" adaptive optics over conventional "closed loop" correction is that the system should be less sensitive to misregistration between the AO correction device and the wavefront sensor. In the conventional feedback AO system (see Figure 1) errors in registration result in the correction being applied at the wrong location and with the wrong size on the deformable mirror. This error is sensed by the wavefront sensor and it attempts to correct this error on the next update of the AO loop. The misregistration results in loss of bandwidth. For sufficiently large misregistration, the AO loop can be become unstable. If the misregistration is sufficiently small, the system will eventually achieve the desired shape on the deformable mirror if the AO loop updates its correction several times before the incoming wavefront changes.

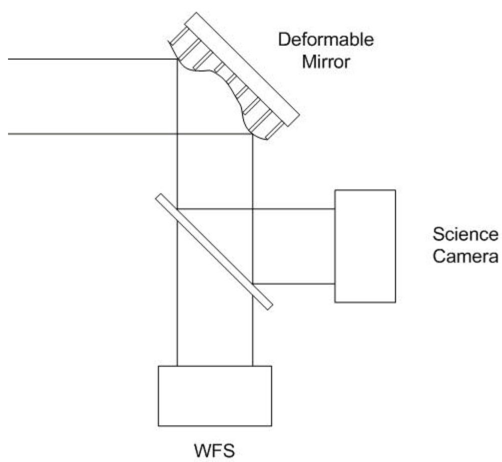

Figure 1: Conventional feedback AO system, shear between the sensor (WFS) and the corrector (DM) results in lose of bandwidth and possibly feedback loop instability. The system can eventually achieve the desired correction if the misregistration is small.

In a pure "go-to" AO system (see Figure 2), the WFS does not "see" the correction that is applied to the deformable mirror. Therefore, the system will apply the wrong correction but this has no effect (feedback) on the wavefront sensor measurement. While the conventional system might eventually achieve the correct shape, the "go-to" system will have a static offset error. The resulting error is a just a shear between the sensed and the applied correction that is similar to angular anisoplanatism or temporal delay with a thin phase screen displaced by fixed amount. We calculate this error in the next section.

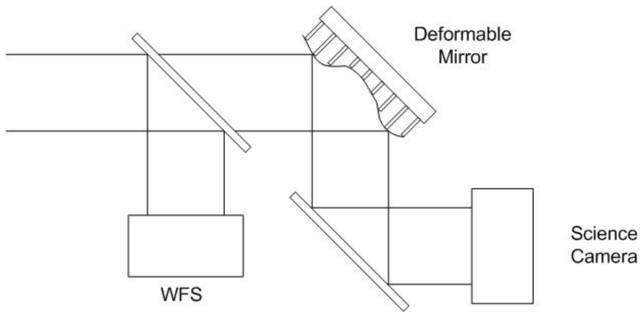

Figure 2: "Go-to" adaptive optics system, shear between the sensor (WFS) and the corrector (DM) results in a static error in the applied wavefront. The system will never achieve the desired correction but instead has a static error in the wavefront.

2. Wavefront error estimation

The misregistration of the DM-to-lenslets in a "go-to" system results in an anisoplanatism type error. The sensed and corrected pupils are laterally displaced by an amount equal to the misregistration, Δr (see Figure 3). The error between two sheared pupils averaged over atmospheric fluctuations can be calculated in a manner similar to angular anisoplanatism.

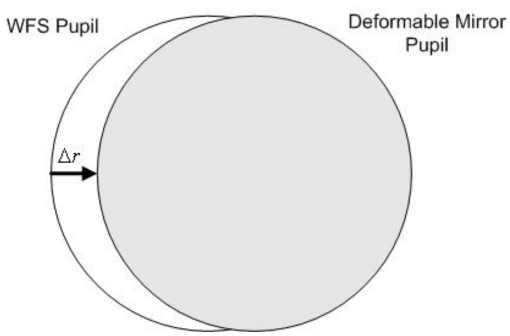

Figure 3: Misregistration between sensor and corrector pupils.

Assuming that fluctuations of input wavefront can be characterized by the Fried parameter r0, and the displacement between pupils is given by a length Δr. Using dimensional arguments, the expected wavefront error (in radians) will be given by:

$$\sigma^2 \propto \left(\frac{\Delta r}{r_0}\right)^{5/3}. \quad (1)$$

The final expression can be derived in the limit of large D/r0 from the standard expression for angular anisoplanatism [1],

$$\sigma^2 = \left(\frac{\theta}{\theta_0}\right)^{5/3}. \quad (2)$$

We replace θ with $\Delta r/h_0$ and assume that the distributed C_n^2 profile is composed of one infinitely thin layer located at height, h_0. The final expression is then:

$$\sigma^2 \cong 6.9\left(\frac{\Delta r}{r_0}\right)^{5/3}. \quad (3)$$

3. Comparison of 'go-to' and conventional closed loop correction

Setting the value r_0 (ref. 500 nm wavelength) to 16 cm, and allowing an allocation for DM to lenslet misregistration of 20 nm rms, the allocation can be met with a displacement, Δr, of 1 cm between the DM and WFS lenslet where the displacement is referenced to the telescope pupil. If the subaperture size is 20 cm then the tolerance is approximately 1/20 of a subaperture spacing, which is comparable to the rule-of-thumb used in conventional closed loop AO systems of 1/10 an actuator spacing.

4. Conclusions

We have shown that the misregistration tolerance in a pure "go-to" adaptive optics system is comparable to the misregistration tolerance in closed loop adaptive optics system. Application of this result to NGAO is complicated by the fact that the large low order deformable mirror (woofer) could be operating in a closed loop mode while the higher order MEMS deformable mirrors are operating in a "go-to" mode. Understanding these effects is beyond the scope of this note.

In addition the "go-to" tolerance can be relaxed by knowing the shift between the sensor and corrector. If Δr can be measured then the wavefront measurements can be "shifted back" in software to the correct registration before it is applied to the deformable mirror. This information could be estimated in a manner analogous to wind estimation algorithms, now under development at CfAO and LLNL. The exact allocation between alignment and calibration for the NGAO systems is also beyond the scope of this note.

References

1. D. L. Fried, "Anisoplanatism with adaptive optics," JOSA, 72, 52-62, 1982.