PIGS –
A New Wavefront Sensor Concept for ELTs

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Abstract. Adaptive Optics Systems for Extremely Large Telescopes (ELT) will need new wavefront sensing concepts to deploy their full capabilities. In this paper we exemplify the necessity of new wavefront sensing ideas by discussing briefly some major problems and present as a possible solution the pseudo infinite guide star sensor (PIGS). A prototype of a PIGS sensor was already built in the laboratory, which could demonstrate its feasibility.

1 Introduction

Ground based Extremely Large Telescopes (ELT) [1], [2] with aperture diameters of up to 100m will deploy their full capabilities only by the means of Adaptive Optics (AO) [6]. But current AO systems are mainly limited due to the low sky coverage with Natural Guide Stars. One possible way to solve this problem is to excite sodium in the mesospheric layer of the atmosphere by the means of a tuned laser and create in this way an artificial guide star. But for ELTs however, the use of Sodium Laser Guide Stars (LGS) [3] produces some difficulties like:

- Perspective elongation: The thickness of the the sodium layer is no more negligible. Therefore the LGS will be seen more and more elongated from sub-apertures with increasing radial distance from the telescope center.
- Defocus: The small focal depth of the WFS relative to the length of the LGS leads to a defocus of the sensed image.
- Temporal gating: Short laser pulses to overcome the problem of defocus will have strong constraints on the pulse length and format and will dramatically reduce the number of photons to sense the wavefront.
- Absolute tilt: LGSs provide no information of absolute tilt. Therefore a NGS is still necessary [4], [5].
- Huge conical anisoplanatism: Due to its finite distance the light of a LGS samples only a cone of the atmosphere instead of a full cylinder as for NGSs.

These problems are mainly related to the finite distance of the artificial star. One possible approach to overcome this, is to treat the light of the LGS as if coming from infinity, what leads to the Pseudo Infinity Guide Star (PIGS) concept.

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2 Layout of the Pigs Wavefront Sensor

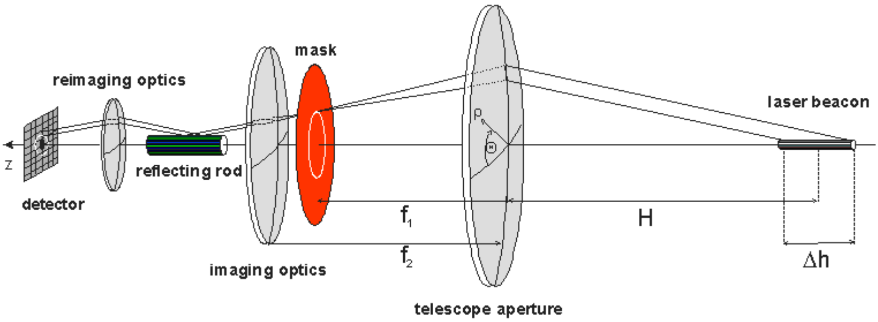

Fig. 1. : Conceptual design drawing of a PIGS sensor using a reflecting rod and a mask with annular slits as sensing devices.

A suitable setup for PIGS-WFS is shown in Fig. 1. It consists of two independently working sensing devices, a mask with circular slits and a reflective rod. The sensor is a pupil plane sensor and measures the second derivative of the incoming wavefront. The rod is placed in the focus of the LGS and senses the azimuthal perturbations, while the mask is located in the focal plane (f1) and measures the radial aberrations.

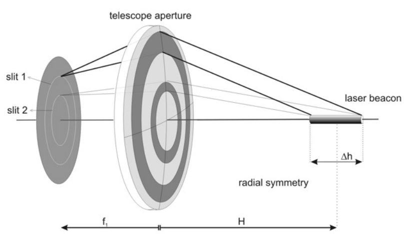

Fig. 2. A mask with circular slits is able to select light with a certain angle radial symmetric to the optical axis

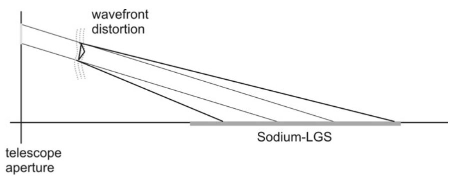

Fig. 3. Depending on the wave front distortion (here approximated with roof like shape) more or less light of the LGS is refracted into the sub-aperture. The sensitivity of the WFS depends on the ratio $\frac{H}{D^2}$

A mask in the focal plane with an annular slit will select light from the LGS coming from a certain direction radial symmetric to the optical axis (see Fig. 2), since a certain point at focal plane is related to one direction in object space. Hence light origin at the LGS and passing the slit seems to be from infinity (pseudo infinity guide star). Any wavefront distortion in radial direction changes the amount of light falling into a slit (Fig. 3). Perturbations in azimuthal direction will not change the amount of light passing the slit. Even a lot of light is blocked by the mask, such approach is collecting per slit the same amount of light as with temporal gating. To increase the efficiency we use several concentric annular slits and select so different angles simultaneously (angular gating, Fig. 2).

In order to sense the incident wavefront in azimuthal directions, we use a reflecting rod. The concept of such a z-invariant WFS was already presented in [8]. The rod placed in the LGS focus reflects a ray without aberration into the same direction while a distorted ray will change its direction with a certain angle (Fig. 4). The rod amplifies azimuthal perturbations and changes therefore the intensity in sub-apertures in the re-imaged pupil. The minimal dimension of a sub-aperture is defined by the rod diameter, since the rod transforms due to the reflection any spot of a finite size into an arc (Fig. 5). This implies some constraints for the realization of such a sensor. The length of the arc is depending on the curvature of the rod, which is defined by radius r.

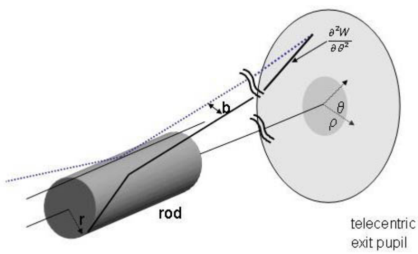

Fig. 4. The rod simply reflects a ray without aberration while a ray with aberration is shifted by an amount b and gets deflected.

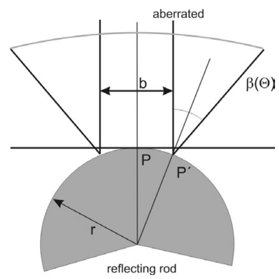

Fig. 5. A spot of the size b reflected by the rod will be transformed into an arc. The angle of the arc is a function of the radius r of the rod

3 Lab Experiments and First Results

An experimental setup of a PIGS sensor was built up in the laboratory and first measurements were done. Since it is impossible to scale down the ELT conditions (100m aperture, 100km distance of LGS) by a factor of 1000 (0.1m aperture, 100m distance of LGS) it was only feasible to test the rod as a wavefront sensing device (The sensitivity of the mask scales with $\frac{H}{D^2}$ and is very small compared to the rod). In order to simulate the atmospheric perturbations we used simple window glass. The aberrations of the glass were measured with an interferometer and were showing more low order aberrations than high order, close to a Kolmogorow distribution. We fitted both the second derivative of the reference data set and the obtained PIGS data with Zernike polynomials up to the 80th order and cross correlated them. This was done with three different phase screens. Although the results were clearly limited by the low surface quality of the reflecting rod a cross correlation of 85%, 78% and 75% could be obtained.

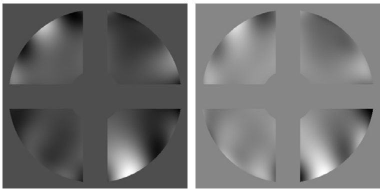

Fig. 6. Pupil images of reference (left) and PIGS (right) data. Both wavefronts were fitted with Zernike polynomials up to the 80th order

4 Conclusion and Outlook

We have shown a new kind of wavefront sensor using LGS with the concept of Pseudo Infinity Guide Stars. An experiment with a part of the WFS was set up in the laboratory and first results obtained. The data correlates very well with independent measurements. The PIGS sensor can overcome several problems known with LGSs and conventional sensing methods and can easily be extended to a MCAO system. By using several LGS each sensing with a full PIGS system. Since MCAO and LGSs will play a major role to deploy the full capabilities of ELTs the PIGS-WFS is an interesting option.

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