Separation of Atmospheric Layers

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ABSTRACT

In between the star-oriented tomographic measurement of atmospheric layers, and the pure layer-oriented one, there is a simple third option, which measures the turbulence in the layers' images proper by a Hartmann-Shack type sensor. The wide field is achieved by looking at multiple stars in each lenslet. The method is simple to use, but requires a fast, sensitive camera with many pixels for the lenslets' wide fields. Most of the empty pixels (without stellar images) are skipped during read-out.

Keywords: adaptive optics, tomography, multi-conjugate adaptive optics, beacons.

1. INTRODUCTION

Various methods are possible for tomographic measurements of two or more atmospheric layers, as required for adaptive optics. After measurement, the separate atmospheric layers can be corrected, all or part of them (single- or multi-conjugate adaptive optics). In very large telescopes these measurements are critical. In the past the methods proposed[1] can be divided into the following categories:

1) Few guide stars, each with its sensor in the pupil plane. Layers are calculated from their shifted geometrical projections.

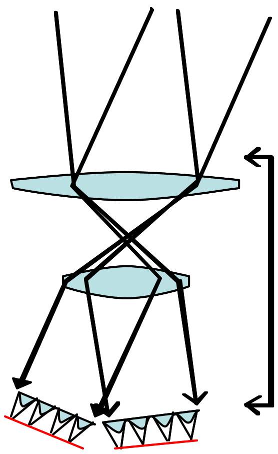

Figure 1: Different sensors, conjugate to the telescope pupil, allow reconstruction of the atmospheric layers.

2) A grid of stars (fringe pattern) with one large Hartmann-Shack sensor in the pupil plane. Each lenslet images many fringes. Layers are calculated from fringe demodulation and shifted geometrical projections. Fourier methods are employed to accelerate calculations.

3) Few guide stars with a pyramid each and few sensors in the layers planes[2]. Magnification is required in order to match the stellar images to the pyramids. While the first method was star-oriented, and the second was both star- and layer-oriented, this last one is really a layer-oriented method. Light from many stars is accumulated optically (rather then electronically) on the detector. This approach should be better in terms of signal-to-noise ratio, and in extremely large telescopes might even be enough for tomography without the benefit of laser guide stars.

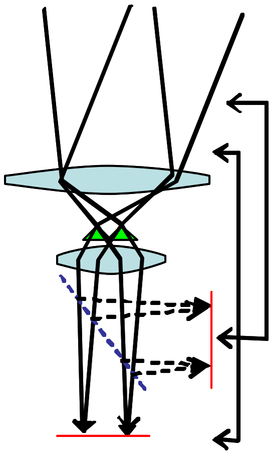

Figure 2: Pyramids, at the images of the beacons, and detectors, conjugate to the atmospheric layers, measure directly slopes in these layers.

4) A grid of stars (fringe pattern, as in Option 2 above) with a grid of matching pyramids and sensors in the layers planes[3]. Because this is a layer-oriented method, the fringe pattern requires only a few watts of laser power (<15). Because this method involves a monochromatic source, it can use blazed gratings instead of pyramids for shifting the beams.

The ideas proposed here[4] are in between these methods. They do image the stars, but they do so in the layers proper:

5) Few guide stars and few Hartmann-Shack sensors in the layers' planes. Each lenslet in the sensor images most or all the stars in the field of view. A beam-splitter separates the beams for the different height conjugates.

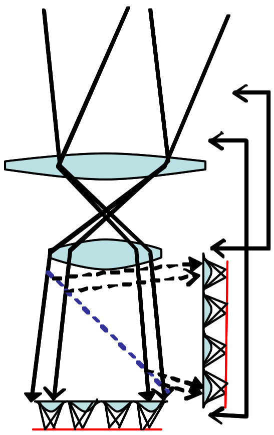

Figure 3: Lenslet arrays, conjugate to the atmospheric layers, measure directly slopes in these layers. The pitch of the lenslets is matched to the atmospheric turbulence.

6) Few guide stars and one sensor alternating between layers' planes. Here the layers are measured sequentially, alternating in time on the same detector. One layer sensor is switched on, then the other one. These sensors are not Shack lenslets; rather they are near-field images of acoustic waves[5]. Otherwise this method is similar to the previous one.

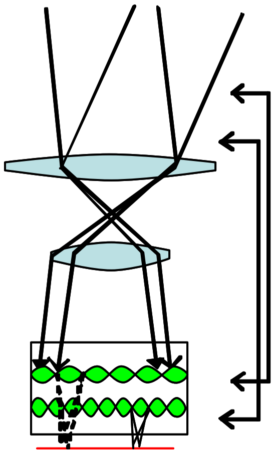

Figure 4: Two alternating acoustic beams, each conjugate to a different layer, saves a beam splitter but divides the detector integration time per layer in two. The two measurements are shown here, even though each one occurs at a different time.

2. DETECTOR

The detector facing the Hartmann pattern (Options 5 and 6) has to image many stars in each lenslet, all those stars fitting in the adaptive optics field of view. Each star or laser spot need be nearly resolved in order to find the global tilt of the wave front in the lenslet. This sets the number of pixels in each lenslet, and hence the number of pixels in the whole camera. The total number of pixels in the wave front camera is equal to that in the scientific camera with the larger field of view[4].

The stars to be centroided only take up a few percent or less of the total number of pixels in the camera. Thus most of the camera pixels are to be skipped during read-out.

3. ANALYSIS

When using a laser guide star, its image will be at a different focal distance and scale as compared to natural stars.

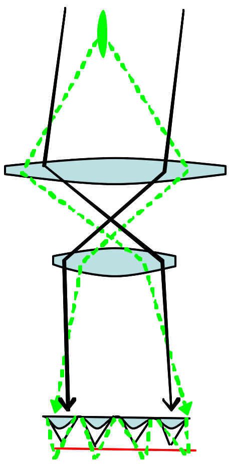

Figure 5: A laser beacon creates a spot pattern which is both spaced and focused differently than a natural one. The detector is positioned in between foci.

The simplest way to separate stellar and laser images is spatial: put each in a different frame and analyse separately.

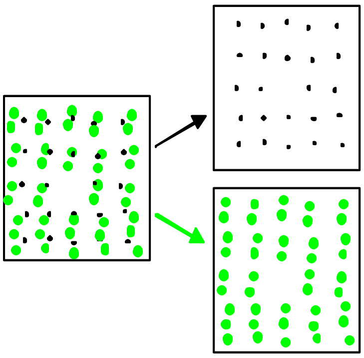

Figure 6: In some cases, the spots will be separated spatially, and hence in software. In cases they are not, the separation will be in the Fourier domain, since they have different spacings.

Another way which is possible is to use Fourier methods. Here the whole frame is transformed, and the *x*- and *y*-tilt data are in the *x*- and *y*-side-lobes of the Hartmann pattern[6]. For adaptive optics there is no actual need to re-transform to the layer plane – the correcting mirror signal is directly taken from these side-lobes.

In this Fourier analysis scheme, the laser spots will be at a different frequency in the Fourier domain, and hence will be separable from the stellar ones.

4. EXPERIMENT

Using the flexible lenslet array[5] in the laboratory, images were taken of a single (a) and a double (b) source. Their Fourier transforms are (c) and (d). We see in the central part of the Fourier domain that the location of the side-lobes remains the same for these two cases.

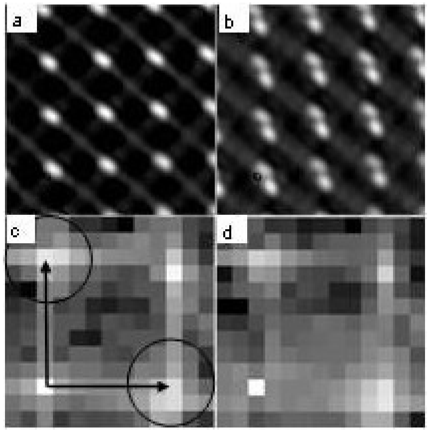

Figure 7: Portions of the Hartmann pattern of single and double spots, and portions of their corresponding Fourier transforms. The lobes used for reconstruction or for adaptive optics are marked in circles.

In an actual adaptive optics system, these Fourier components in the circles contain all the necessary information about the gradient of the wave front, and hence are sufficient to build a control matrix through them.

Indeed, a closed loop adaptive system (for one layer only) was constructed in the lab and successfully run using only the Fourier transform of the Hartmann spots, without their prior centroiding.

5. SUMMARY

The configurations described here are somewhere in between the star-oriented and the layer-oriented approaches. As such, they have the following attributes (notice that there are more advantages if Fourier processing and/or the acoustic detection are applied) :

Disadvantages:
• Large cameras: the wave front cameras hold as many pixels as the science cameras with the large field, but are to be read much faster. Most (empty) pixels are dumped during read-out.

• Signal to noise issues: the SNR might be lower than the pyramid layer-oriented method, since each star is spread between many lenslets. The number of the effective lenslets scales inversely with r_0 of the layers.

Advantages:
• Simplicity of construction: imaging of separate layers on different Hartmann sensors.

• Simplicity of implementation: using a single detector and single acoustic Hartmann cell to switch between layers electronically.

• Matching the turbulence: setting the acoustic frequencies, or the Hartmann pitch, to match the layers' r_0.

• Simplicity of analysis: straightforward demodulation of periodic pattern in Fourier domain.

• Speed: Fourier processing is faster than centroiding.

• ELT-ready: Fourier methods scale more easily to larger telescopes.

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6. REFERENCES

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