The Adaptive Optics Module for TNG (AdOpt@TNG): A Status Report

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ABSTRACT

The status report of the adaptive optics module for the 3,5m TNG telescope is briefly given together with the description of three important subsystems: the off–axis tracking capability of the wavefront sensor; the CCD to be used for the wavefront sensor and the modal filtering approach to be implemented in the module.

1. INTRODUCTION

In this paper we give the status report of the Adaptive Optics system for the National Telescope Galileo (TNG). A full description of the system can be found elsewhere[1] while here we wish to point out some interesting feature of this module. The first–light of this instrument, currently under construction, is expected in April 1996. At the very first phase it will allow for tip–tilt correction only. However most of the optical system, alignment, and of the informatic structure is common to both tip–tilt and higher order correction. With this choice we hope to solve most of the problems connected to the construction of such a complicated instrument in the very first step, where the required correction is attainable with a limited amount of efforts. The tip–tilt sensor and the tip–tilt mirror, the essential pieces of the first–light correction system, are now in advanced stage of realization and some account on these is given elsewhere[2,3]. In the following attention is paid to the capability to track in a differential manner the science and reference objects; to the CCD detector to be adopted for the high order wavefront sensing and to the matricial approach used for the modal filtering in the WaveFront computer of the AdOpt@TNG module.

Memory Area	80 × 80 pixel
Image Area	80 × 80 pixel
Pixel Size	24μm × 24μm
Physical Area	1.9mm × 1.9mm
Output Channels	4

Table 1: The characteristics of the CCD to be used for AdOpt@TNG wavefront sensing.

2. DIFFERENTIAL TRACKING FOR SCIENCE AND REFERENCE OBJECTS

The optically corrected Field of View (FoV) of the AdOpt@TNG module is one arcmin squared[4]. However the wavefront sensor can locate any object within this area. In other words between the center of the FoV on the scientific detector and the reference object used by the wavefront sensor an adjustable offset can be introduced. This is accomplished through a micrometric–driven mirror between the dichroics wheel and the wavefront sensor itself. Because of the possible errors in positioning these reflecting surfaces an intensified camera will be able to look a small portion of the FoV covered by the wavefront sensor.

The interesting feature of this additional reflecting mirror, as it has been designed, is that it would provide an additional and programmable differential movement between the wavefront sensor and the scientific camera. It is suitable, in this way, to use moving objects as a reference source, as suggested by Rigaut[5] or to use natural stars to correct for moving scientific targets, like comets.

The optical lever of this mirror is very small (roughly 200mm) in order to relax the tolerances on the positioning of this unit with respect to the expected resolving power of the telescope with the closed Adaptive Optics loop.

3. THE CCD DETECTOR FOR WAVEFRONT SENSING

The CCDs camera for the TNG telescope belongs to the scientific cameras for imaging and spectroscopy, to the tracking and Shack–Hartmann (SH) analysis for Active Optics (AOPT) purposes, and to the detector for high order analysis Adaptive Optics (ADOPT in this section). While most of the functionality and characteristics of the CCD controller, for istance, of the various cameras are common, there are some essential differences within the ADOPT WF sensor camera and the AOPT system. The main distinctions are here summarized:

- the ADOPT analyzer will work at short frame periods compared to the AOPT system (some *ms* compared to tens of *s*),
- the ADOPT analyzer will work with a small number of subpupils compared to the AOPT system (4×4 up to 16×16 compared to 10×10 up to 40×40).

The frame rate imposed by the ADOPT system gives the requirement to have the minimum of readout-noise and the best sampling of SH spots PSF in order to peak the overall sensitivity. As a result CCD chips for ADOPT purposes are characterized by very small number of pixels (64×64 is a typical case), very high gain output stage and SH spots are sampled directly at the center of four neighbouroud pixels (macro quadrant cells). EEV is producing under contract a special CCD for this application with parameters shown in Tab.1. The chip, named EEV39, will be processed for quantum efficiency (QE) enhancement and delivered with the EEV42 chips. It is predicted to have a noise of less than 5 electrons up to 1 MHz pixel rate and less than 2 electrons with optimized sampling time.

The macro cell readout mode is obtained using extensively the horizontal and vertical binning capabilities of the CCD. Assuming to read a 4–quadrants macro–cell with pedestal reading for each of these subapertures a total of 10 readouts (I.E. ADC conversions), composed by 6 vertical and 24 horizontal shifts are required in order to complete a macro cell scan.

The detector controller sequencer must provide enough flexibility in order to accommodate such kind of readout. Further details can be find elsewhere[6].

4. THE MODAL FILTERING APPROACH

Because of the different temporal evolution of the wavefront deformation modes (like the Zernike polynomials, for istance) and of the different achievable SNR in their estimation, it is clear both from a theoretical[7,8] and experimental[9] approach that a mode–dependent filtering is a cost–effective approach. In the following we do not discuss further this last point but we point out that through a matricial approach one can handle any type of modal–dependent filtering adopting as WaveFront computer a general purposes matrix multiplier.

Let us suppose that the derivative of the wavefront is sampled at $n+1$ points both along x and y direction, being the derivative estimates denoted by the matrix S. It is straightforward to show that does exist a matrix $[S \rightarrow M]$ able to transform these data into $m+1$ modes coefficent:

$$\begin{bmatrix} S_0^x \\ \vdots \\ S_n^x \\ S_0^y \\ \vdots \\ S_n^y \end{bmatrix} \times [S \rightarrow M] = \begin{bmatrix} M_0 \\ \vdots \\ M_m \end{bmatrix}^T \tag{1}$$

The index T is here used to indicate that the matrix is transposed. On the other hand there exist a matrix $[M \rightarrow \phi]$ able to give the wavefront displacements ϕ distribuited in a given array of p points on the pupil. These figures directly commands the deformable mirror in the AdOpt@TNG module. The last statement can be written as:

$$\begin{bmatrix} M_0 \\ \vdots \\ M_m \end{bmatrix} \times [M \rightarrow \phi] = \begin{bmatrix} \phi_1 \\ \vdots \\ \phi_p \end{bmatrix}^T \tag{2}$$

One can think to have an array of modes depending upon the time $[M_t]$. One can, furthermore, think to apply to this object some filtering and obtain a filtered object that will be denoted by an f pedice. $[M_t]$ can be easily obtained via the following:

$$\begin{bmatrix} S_t \\ S_{t-\Delta t} \\ \vdots \\ S_{t-k\Delta t} \end{bmatrix} \times \begin{bmatrix} [S \rightarrow M] & & & \\ & [S \rightarrow M] & & \\ & & \ddots & \\ & & & [S \rightarrow M] \end{bmatrix} = \begin{bmatrix} M_t \\ M_{t-\Delta t} \\ \vdots \\ M_{t-k\Delta t} \end{bmatrix}^T \tag{3}$$

where the block–diagonal matrix composed by several identical $[S \rightarrow M]$ blocks is identified in the following by a tilde:

$$[S_t] \times [S \overset{\sim}{\rightarrow} M] = M_t \tag{4}$$

Filtering of the i–th mode using as input the mode estimated at the time $t - j \times \Delta t$ is individuated, for example, by the Finite Impulse Response (FIR) filter f_{ij}. In this way one can write:

$$\begin{bmatrix} M_t \\ M_{t-\Delta t} \\ \vdots \\ M_{t-k\Delta t} \end{bmatrix} \times \begin{bmatrix} f_{01} & & & \\ & f_{02} & & \\ & & \ddots & \\ & & & f_{0m} \\ f_{11} & & & \\ & f_{12} & & \\ & & \ddots & \\ & & & f_{1m} \\ \ddots & & & \\ & \ddots & & \\ & & \ddots & \\ & & & \ddots \\ f_{k1} & & & \\ & f_{k2} & & \\ & & \ddots & \\ & & & f_{km} \end{bmatrix} = \begin{bmatrix} M_0 \\ \vdots \\ M_m \end{bmatrix}^T \tag{5}$$

or, in a more compact form:

$$[M_t] \times [\mathrm{Fir}] = [M_f] \tag{6}$$

At this point it is easy to show that the whole process starting from the time dependent slope estimations $[S_t]$ produced, for example, by a Shack–Hartmann wavefront analyzer, can be described by the single large matrix $[K]$ defined by the following relation:

$$[S_t] \times [S \overset{\sim}{\rightarrow} M][\mathrm{Fir}][M \rightarrow \phi] = [S_t] \times [K] = [\phi_f] \tag{7}$$

In the working system the matrix $[K]$ is computed in an off–line process using the most of the data collected by the system (r_0, f_G, sampling of the pupil, SNR of the reference object, etc.) and provided to the real–time system. The latter should only allow for very fast multiplication of such large matrices. In this way both a strong flexibility and relatively simplicity of the wavefront computer hardware can be attained.

5. CONCLUSIONS

Three *unusual* features of our Adaptive Optics module has been outlined. Following the current schedule we expect to give performance report on the sky of some components of the module in one year and to have the first early scientific results slightly after.

ACKNOWLEDGEMENTS

The AdOpt@TNG module is becoming a reality thanks to the large efforts spent in its initial phase of development by Domenico Bonaccini, now at ESO; the group of Arcetri (Simone Esposito, Luca Fini and Piero Ranfagni) is in charge of most of tip–tilt subsystem; the staff at the Asiago Observatory (Giovanni Baú, Giovanni Costa, Sergio Dalle Ave, Antonio Primon and Italo Rigoni) worked out a number of components of the module. Thanks are due to all of them.

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