AdOpt@TNG: an update
R. Ragazzoni, A. Baruffolo, F. Bortoletto, M. D'Alessandro
Astronomical Observatory of Padova
vicolo dell'Osservatorio 5, I–35122 Padova (Italy)

J. Farinato, A. Ghedina
Department of Astronomy, University of Padova
vicolo dell'Osservatorio 5, I–35122 Padova (Italy)

S. Mallucci
Department of Astronomy, University of Bologna
via Zambon 33, I–40126 Bologna (Italy)

E. Marchetti
Center for Studies and Space Activities “G. Colombo”
via Venezia 1, I–35131 Padova

ABSTRACT

AdOpt@TNG is the Adaptive Optics module for the Italian “Telescopio Nazionale Galileo” (TNG), a 4m-class telescope that will have its first light in late 1997. This module incorporates a number of peculiar features such as the adoption of an electro-magnetically driven tip-tilt mirror, a continuously adjustable offset between the reference and the scientific objects (in a way to deal, for instance, with moving references, like asteroids, or targets, like comets), a built-in speckle camera with an on-line autocorrelator and others. The speckle camera has been tested at the 1.82m telescope of the Astronomical Observatory of Asiago, a short account of the results obtained is given. Most of the elements of the AdOpt@TNG module have been manufactured and tested. The up-to-date status report of the module is briefly given.

1. INTRODUCTION

In February 1996 the Italian National Council for Astronomical Research decided to fund the Adaptive Optics module for the Telescopio Nazionale Galileo®1, a 3.5m telescope facility erected in Roque de Los Muchachos (Canary Island). In this paper we will give a brief account on the status of the project, focusing on some of its features that somewhat lie along a different line with respect to other similar projects. Namely, AdOpt@TNG is a Shack–Hartmann based module² capable of sampling the pupil with up to 8 × 8 subapertures. The tip-tilt loop correction is kept on a separate basis so that it can eventually support the option of a Laser Guide Star.
2. THE OPTICAL BENCH

Most of the AdOpt©TNG module is built over a 1500 x 900 mm² metric optical bench which is vertically mounted at the imaging Nasmith focus through a mechanical piece called Nasmith Interface. The Nasmith I/F is rotated by the Rotator/Adapter in order to counteract the rotation of the Field of View. The same mechanical piece holds the Optical Imager and the Infrared Camera for scientific observations.

In Fig. 1 a detail of the two folding mirrors located in the F/11 converging beam of the TNG optics is shown. The two mirrors are mounted on a sliding rail allowing for a fast introduction of the AdOpt©TNG optical path into the scientific cameras. One of the two mirrors can be further positioned in order to fold the outcoming light from AdOpt©TNG toward the visible or the infrared channel.

Both mirrors have been interferometrically tested to be flat with λ/40 quality. The first one has been silver coated in order to enhance the near-IR reflectivity, while the second one is Aluminum coated because it is used only in conjunction with the CCD camera which operates in the visible.

The passive part of the AdOpt©TNG module is a magnifying all-reflective optical relay made up by two off-axis Silver coated parabola, manufactured by SORL and Optical Surfaces, characterized by an optical quality of λ/20 and by having constant edge thickness. The coating, provided by the Italian firm CeTeV shows a remarkably good reflectivity in the wavelength range of interest (see Fig. 2).

Because of the constraint to use the same scientific cameras both for direct and adaptively compensated imaging, a solution for the optical relay with the principal rays lying into two different planes is required. In Fig. 3 the overall optical path is shown on a laboratory optical bench. We have found very convenient to deploy most of the pieces on this table until the various elements and their mechanical interfaces are mounted on the final optical bench. On the same laboratory table a telescope simulator has been set up and it is used to illuminate at F/11 the optical train.
The optical train is undergoing various checks for the off-line and on-line alignment. In fact we proceed with two different approaches during the mounting of the optics and during the expected operational lifetime of the instrument.

In the so-called off-line mode the F/32 foci can be accessed, provided the IR camera is not mounted. Moreover it is expected, at this stage, that the optical elements will be far from the nominal position by distances as large as a few millimeters. In these conditions a preliminary geometrical adjustment is to be performed. During this phase a careful assessment of the distortions will take place.

After an initial pre-alignment a partial interferometrically supported alignment can take place. At this phase the rotation of the off-axis parabolae with respect to their own optical axes will be frozen. From our ray-tracing simulations, in fact, we do not expect to have any further re-alignment of this degree of freedom (unless the optics are temporarily dismounted from the optical bench).

Once the off-line alignment has been properly performed, an on-line alignment capability has to be provided. This is especially required if one takes into account that an independent refocusing of the scientific camera with respect to the module's optical relay is required. The latter is accomplished by moving the second off-axis parabola. Accurate tip-tilting of this optical element is obtained through motorized screws.

Feedback is obtained by the wavefront sensor and by reimaging four fiber ends that can be illuminated and placed instead of the field diaphragm at the F/11 telescope's intermediate focal plane.

Figure 2: The reflectivity curve of the Silver coating of the two off-axis parabolae.

Figure 3: The optical bench with the F/11 to F/32 optical relay illuminated by an HeNe laser.
**Optical Relay**
- F/11 Field: Diaphragm field, alignment fibers or WF Simulator relay
- Focus OAP2: Independent refocusing of the optical relay
- Align OAP2: Tip-tilt of the second off-axis parabola for alignment
- Folding mirror: Selection of visible or infra-red scientific camera

**WaveFront Sensor**
- Neutral filters: Selection of 8 neutral filters for APDs
- Acquisition: Selection of the mask for star acquisition
- OffsetXY: Selection of the offset wrt the scientific camera axes
- DriftXY: Relative drift (useful to track solar system objects)
- Acq Camera: Switch On/Off the acquisition intensified CCD
- Acq Gain: Set the gain of the Acquisition camera intensifier
- WFS Mode: SH mode (4 x 4 or 8 x 8) or pyramidal mode

**Speckle Option**
- Beam: Fold the mirror to feed the light to the speckle camera
- Speckle filters: Select one of the 8 scientific filters
- UV coverage: Select the UV selection mode on the pupil
- Speckle camera: Switch On/Off the speckle intensified CCD
- Gain speckle: Set the gain of the speckle camera intensifier

**Fizeau Interferometer**
- Fizeau camera: Switch On/Off the Fizeau camera for fringes acquisition
- XYFizeau: Displace the reference mirror in the Fizeau interferometer

**WaveFront Simulator**
- Greenwood freq: Set the apparent Greenwood frequency
- D/ro setting: Changing the internal beams to vary the apparent r_0
- Z-Layer: Change the apparent altitude of the highest layer
- Set Object: Select the object to be imaged into the WF simulator

Table 1: The different axes driven inside the AdOpt@TNG module are here listed, grouped by the type of services they belong to.

The four fibers are arranged in a way that one is on-axis and the other three lie in a one arcmin diameter circle, 120 degree apart from each other.

The module has several axes to mechanically drive a number of optical components for different purposes. These are listed in Tab. 1 and deserve some comments here.

The more demanding positional accuracy has been accomplished through absolute encoders based upon a gray optical mask for the rotative case and by means of a wire-driven absolute multi-turns encoder for the linear case. The last technique has been chosen because it gives a greater flexibility in positioning the encoder unit. Repeatability can reach a few μm over a range of 100mm and thermal dependence can be kept as low as required by the optical constraints of our module. More relaxed positional accuracy in the linear domain has been obtained through high precision potentiometric slides and a 12 bit A/D converter. Finally, for other axes only an On/Off feedback through proximity sensors is foreseen. The whole driving system is controlled by a standard rack-mounted industrial PC, provided by the Italian firm AITEM. Commands can be sent to the control system through a standard RS-232 serial line, allowing for either remote and local operations by means of a portable terminal.
3. TOWARDS THE HIGHER LOOP CLOSURE

During the last year we issued two different Calls for Tender both for the WaveFront Computer and the Deformable Mirror. The WaveFront Computer contract has been assigned to ThermoTrex Corp, San Diego, that proposed a VME–based computer using some C40 DSP boards as slope computer and re–organizer of the incoming data, and a dedicated board for the Real Time Reconstruction of the WaveFront. Following our specifications the whole WFC is able to perform separate Finite Impulse Response filtering over a modal decomposition of the acquired wavefront. Through the proper reorganization of the input data both a standard Shack–Hartmann and a Pupil–Plane WF Sensors can be accommodated. The DM contract has been assigned to Xinetics for the 97 actuators unit. For the WaveFront Sensor we acquired an EEV–RGO 80 × 80 low–noise CCD (shown in Fig. 4). Tests for the true read–out noise at the pixel clocking frequency able to give roughly one thousand frames per second are undergoing during this summer. The CCD controller and the interface towards the WFC are under development by the Italian firm ElettroMare.

4. THE SPECKLE OPTION

The AdOpt@TNG will be also equipped with a Speckle Camera able to work independently from the adaptive wavefront correction provided by the module.

It is foreseen that the Speckle Camera will provide real–time autocorrelation of astronomical objects achieving the angular resolution given by the diffraction limit of the telescope aperture. The observational wavelength bandwidth is in the visible and particular care has been taken to have a suitable sensitivity in the blue part of the spectrum, in order to perform high angular resolution observations at those wavelengths classically not useful for adaptive optics.

This facility consists of many different sub–modules: a magnification system, a filter wheel, an acquisition camera and the real–time processing unit.
The architecture of the acquisition system and data processing is shown in Fig. 5.

The magnification system has two objective lenses for two different magnification factors: the first provides a 5× scale enlargement, this requirement matches the Nyquist criterion to have two pixels covering an Airy disk size. The second objective provides a 1:1 scale which is useful to check the correction performances of the AdOpt@TNG without using the scientific cameras.

A filter wheel provides eight narrow band filters for bandwidth selection for different scientific targets listed in Tab. 2; the relative transmittance curves are shown in Fig. 6.

The acquisition camera is a microchannel plate double stage intensified S-25 photocathode coupled to a CCD with an optical fibers bundle. The useful wavelength range is between 360 and 850nm with a maximum of efficiency at 550nm.

The video signal of the camera (CCIR, a standard B&W at 25 frames/second) is sent to three different frame grabbers plugged into three industrial, single board, CPUs. A dedicated multiplexing device triggers the grabbers and allows them to receive only one frame among three coming from the camera. After digitization, the related CPU (operating at 166MHz) processes the frame by rebinning, Fourier transforming and accumulating it. In this way the time needed to perform real-time processing and to reach a full 25 frames per second autocorrelation function accumulation is relaxed.

After a convenient accumulation time the three sets of images are co-added in one of the processors and fed to the system.

Preliminary tests at the 182cm telescope located at the Asiago Astronomical Observatory station have been performed. We were able to resolve double stars up to mV ≈ 10, close to the diffraction limit of that telescope using exposure times a few seconds long, under poor seeing conditions.

5. CONCLUSIONS

The overall layout of the AdOpt@TNG module has been sketched out. Most of the components have been acquired or they are being developed under contract. We expect to have several engineering runs in the coming year at the telescope focus, where a detailed assessment of the performances will be obtained.

<table>
<thead>
<tr>
<th>$\lambda_0 [nm]$</th>
<th>$\Delta \lambda [nm]$</th>
<th>Name</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>475</td>
<td>30</td>
<td>$b$</td>
<td>colored glass filter</td>
</tr>
<tr>
<td>547</td>
<td>30</td>
<td>$y$</td>
<td>long-pass and band pass filters coupled</td>
</tr>
<tr>
<td>550</td>
<td>10</td>
<td>C$_2$</td>
<td>Swan C$_2$ absorption band</td>
</tr>
<tr>
<td>570</td>
<td>10</td>
<td>C$_2$cont</td>
<td>continuum adjacent to the C$_2$ band</td>
</tr>
<tr>
<td>650</td>
<td>10</td>
<td>ZrO</td>
<td>ZrO absorption band</td>
</tr>
<tr>
<td>670</td>
<td>10</td>
<td>TiO</td>
<td>TiO absorption band</td>
</tr>
<tr>
<td>660</td>
<td>10</td>
<td>H$_2$ and NII</td>
<td>emission lines</td>
</tr>
<tr>
<td>580</td>
<td>100</td>
<td>wide-band</td>
<td>this transmission profile is obtained by cutting the camera sensitivity at longer wavelength by means of a short-pass filter</td>
</tr>
</tbody>
</table>

Table 2: The filters adopted in the TNG speckle camera.
Figure 5: Architecture of the real-time speckle option.
Figure 6: Effective transmittance of the selected filters for the speckle camera.

6. ACKNOWLEDGMENTS

Special thanks are due to F. Fusi Pecci and to C. Barbieri for their support to us and to this project. G. Bau, L. Traverso, G. Costa and L. Di Giorgio, of the Astrophysical Observatory of Asiago, kindly assisted us in a number of delicate phases of the module development. The group of Arcetri has taken care of most of the tip-tilt control loop.

7. REFERENCES


