The new active optics system of TNG

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ABSTRACT

Since 1999 the National Telescope Galileo (TNG) is offering observative nights to the astronomical community. With the aim of increase the efficiency of the telescope and minimize downtime many changes have been done from the original project. Recently it has been taken the decision to completely renew the electronic hardware and software of the active optics system, essencially based on VMEs and on the obsolete transputers processors. From the optical point of view some important modifications have also been implemented in order to allow the off-axis Shack-Hartmann analisys. Also the CCD cameras and their controllers have been redeveloped and the whole control software has been ported to a new architecture to by-pass the VMEs system and directly interact with the actuators and the CCD controllers.

Keywords: Active Optics, TNG

1. INTRODUCTION

The TNG[1] initial characteristics were derived from those of ESO NTT: an AltAZ telescope with a Ritchey–Chretien optical configuration. It has an active optics[2] system of 78 actuators (3 of which are fixed) on the back of the primary mirror, an exapod system for the secondary mirror and three piezoelectric actuators for tip–tilt corrections at small temporal frequencies for the tertiary mirror. The control system of the whole active optics is based on a custom made transputer network[3] with associated electronic.

The autoguiding pointing and tracking of the telescope are performed through the Rotator/Adapter system, also called Derotator, one for each Nasmyth focal station. Each derotator has two mechanical probes to carry optics into the field and pick–up the light for tracking and for active optics analisys,[4] through a 25 × 25 Shack–Hartmann lenslet array.

From the original design of the system many upgrades have been done driven by several needs, some practical and some scientific, like the possibility to by–pass many inputs from the telescope user, giving more simplicity in use, or just updating the telescope with new technology for easyness in maintenance and fixing.

In the following we try to detail what have been the main changes introduced so far.

2. THE NEW TILT OF THE PROBE MIRROR

The TNG is not a telecentric optical system: this means that the pupil is not re–imaged at the infinity, and in different points of the field the chief rays are not coming parallel to the optical axis but with a certain amount of tilt. Especially for the optics of the derotator,[5] where tracking and Shack–Hartmann (SH) analisys are performed, if this tilt is not properly compensated, it produces a lot of vignetting into the final images. This is also due to the fact that the beam compressor for the reimaging of the pupil over the lenslet array is not refractive (like for the NTT optical design) but reflective, in a Maksutov–like configuration with a central obstruction. If the beam is not perfectly centered and aligned to the beam compressor the obstruction of the telescope and of the beam compressor do not overlap and the final image is unusable.

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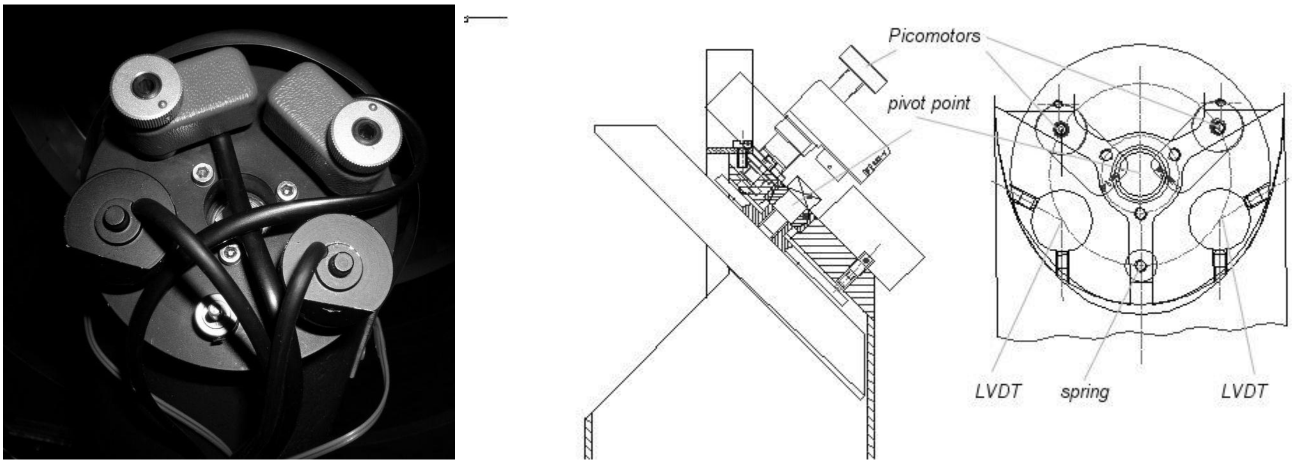

Figure 1. Left: The back of the SH probe, modified in order to compensate for the tilt of the beam when off–axis. One can see the two picomotors (upper side) and the two LVDTs. Right: The detailed drawing of the position of actuators, LVDT and spring on the back of the probe.

The latter turned out to be a major drawback when trying to do active optics corrections during scientific observations: if the pick–up mirror for the SH analysis was not in the center it was not possible to obtain a decent pupil image for the analysis. The effect is the same for the tracking side of the derotator but no pupil images are needed, so it is possible even with the vignetting, to point and guide also off–axis.

We have overcome this constraint modifying the support of the first mirror of the SH probe, the mirror that directly receives the light from M3 and bends it into the derotator plane.

The movements of the mirror are provided by two New Focus Picomotors,[6] a piezoelectric driven screw system which allows sub micron step positioning. The Picomotors push on the invar support glued at the back of the mirror at a radial distance of 28mm from the pivoting point. The counter force for maintaining the mirror in its position is given by a pre–loaded spring, pushing on the mirror support at the same radial distance. The three actuators, 2 active and 1 passive, are placed 120deg apart one another. See Fig.1 for reference.

The position of the probe mirror is given by two LVDTs (Linear Variable Differential Transformer): each of them is properly placed in order to measure the movement of only one Picomotor, that means as respect to the pivot point, on the opposite side and at the same distance. In this configuration when one of the actuators moves out, the corresponding LVDT moves in, and viceversa. The other LVDT should not be influenced by this movement, because the mirror tilts around the axis connecting the pivot point and the other Picomotor. However this is just the theory as frictions and mechanical tolerances in the spring, in the pivot point and in all the interfaces between the invar and the Picomotors, or the LVDTs, inevitably moves both LVDTs.

As a whole, the tilt system of the mirror is controlled in a closed loop between the Picomotors and the LVDT running on a dedicated board. The microcontroller on the board is the RabbitSemiconductor RCM3000 (one can find something more about it in the following section) which receives, via ethernet link, the target position for the probe mirror, drives the Picomotors and closes the loop with the LVDT, until the mirror is in its position.

It must be noted that even if the tilt of the probe allows for the recentering and alignment of the beam along the optical axis, thus removing most of the vignetting, the final pupil image, when off–axis, will be affected by more vignetting than in the center of the field, due to the not perfect overlap of M2 and M3 when seen sideways, and by third order field astigmatism, typical of Ritchey–Chretien and other two–mirrors telescopes.[7] These effects must be taken into account when applying the SH algorythm for the reconstruction of the wavefront.

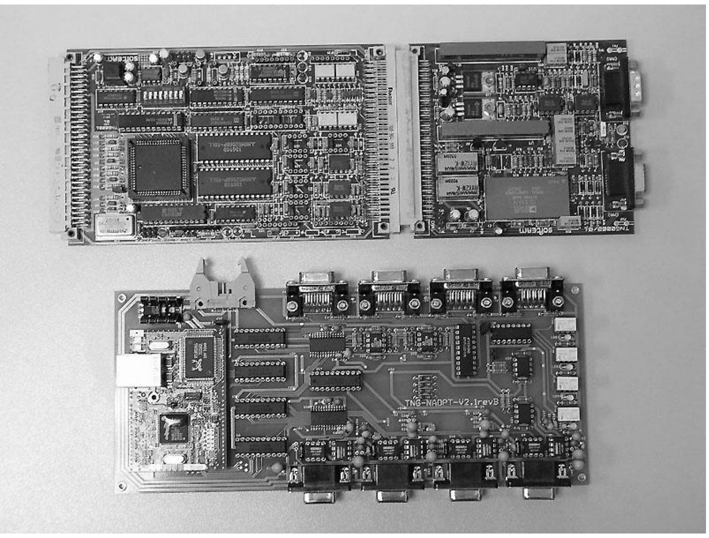

Figure 2. The old (upper) and the new controller boards for the active optics system of TNG. The new one can control up to four actuators, that is a reduction factor of 4.

3. THE NEW ACTIVE OPTICS CONTROL NETWORK

The transputers system for the active optics of the TNG[3] has shown to be a stable and well designed system, and we have never experienced great problems if not for the lifetime of the electronic controlled by the transputer processors, which had been custom made, and neither of them is now no longer supported. The first drawback we experienced has been then to run out of the electronic spare parts for the transputers boards and as a direct consequence we found the lack of technical support when trying to perform any kind of fixing: this forced us to take the decision to update and redesign the whole electronic control system of the actuators.

The change was done with three premises: first, to develop the new system as quickly as possible (because the old cards were dying); then, to look for standard technology that was not going to die in a short term; and finally, to benefit from 10 years of electronics in size and weight reduction. Another important constraint has been to do all the changes while keeping the operativity of the telescope, which also means that our human and time resources were splitted between maintenance of the old system and research and development for the new one.

The overall result we achieved was not the maximum attainable because we kept the DIP (Dual In–line Package) technology, instead of passing to SMD (Surface Mount Devices), in order to allow any change in house, and we got a size reduction factor of 4 for the boards.

As we said previously, the RCM3000 is the microcontroller selected for the new boards due to the integrated ethernet controller. Thanks to this we didn't need to develop a CAN (Controller Area Network) or any other communication architecture (a good advantage for the time constraint we had). Furthermore we kept one of the good points of the transputer network: the easy interconnection between them thanks to their digital links.

At the moment, with each board we can control 4 actuators of the primary mirror so we just need to link 19 microcontrollers instead of 76 as it was before, with the transputers. This change also allowed us to avoid using a back plane, formerly needed to link and power the transputer boards. The link now is achieved using standard ethernet switches. In this way we think we have a well standard system based on ethernet technology that hopefully will be alive for a long time.

As far as the exapod of the secondary mirror is concerned, we have planned to reduce the size of each board instead of reducing their number; at the same time in the new design we wanted to increase the accuracy of the movements in order to be able to apply focus, tilt and coma correction during scientific observations, an operation that previously was not allowed for the rough step movements of each bar.

4. THE PORTING TO LINUX

The initial choice of using HP–Unix workstations for the WSS–TNG control System Software,[8] was right at the moment of setting up the system, but with time and especially with the improvements of technology, the maintenance and the updating of the machines turned out to be too much demanding in money and in time for the budget of TNG.

The substitution of the HP–Unix Active Optics machine with a PC–Linux computer seems the best solution at the moment, in particular as far as future scalability of the system and flexibility of the software development are concerned. Let alone the advantage of the work of the whole linux–community. Another reason to upgrade the system is to get benefit once again of the new technology that imply greater network bandwidth, faster processors and more memory availability.

The new high level PC–Linux is used to manage the whole active optic system. The 2 basic tasks the new PC has to perform are to communicate with the low–level electronic system via ethernet link (the network of Rabbit of the previous section) and to display to the user the status of the system and receive inputs through the GUI interface, actually developed under IDL. In this way we can remove the VME systems too, as they are too old and we have got very few spares.

The use of a VME to control the transputer boards was not necessary for real–time purposes but to keep a standard configuration in the way in which the commands flow from the high level system (HP workstation with WSS software) to the low-level system (electronics with transputers), and in the way back for telemetry data.

Now the electronic systems are being renewed as well as the WSS software has been ported to a Linux–PC machine, and we needed to define a new standard to comunicate both worlds. The conclusion has been that VME is no longer needed as the connection between the new microcontroller and the external world is done via a TCP/IP protocol, and the PC with a standar network card can *talk* to it directly without the need of an interpreter as it was with the VME.

Rabbits work as bridges and the GUI only have to send messages to the Rabbits that is in charge to interpret the commands and pass through the digital or serial ports the right signals to the electronics, and eventually close a low level loop with backward telemetry.

The business logic is part of the GUI and this one is in charge to save the telemetry data in a database for future use. Everytime an error occurs, the business logic has to manage it. The electronic boards are needed only to serialize commands, to close the low level loops (motors–encoders) or to solve mechanical errors.

The complexity of the system has been reduced to the control of network flows between electronics, GUI and a DB. In a near future we are planning to separate business logic from GUI and from the database. This approach would reflect a three tier layer.

The core of the GUI interface will be written using IDL. IDL allows to combine very powerful tools for image analysis in order to perform, for example, Shack–Hartmann analysis, and gives simple tools to construct and manipulate graphical user interface using widgets and object-oriented programming.

The IDL–Java bridge, which allows to acces Java object within the IDL code, will be used to comunicate with the low level software that controls CCD camera, actuators, sensors, light sources etc.

The communication will be realized using Java class sockets. There will be two sockets: one to send commands and receive telemetry, errors and messages; and another one to transfer the CCD images. The messages, commands and telemetry will be exchanged between the GUI and the control software using an XML-like syntax.

5. THE NEW CCD CONTROLLER

The new generation CCD controller is an evolution of the controller in use at TNG.[9] The same philosophy and technological improvements guarantee an increase in performance and a full compatibility with the previous version. The change involved the host interface, the communication link, the sequencer, the bias generator, the clock generator, the preamplifier and the signal processing. The new interface with the host computer is based on a high-speed link and PCI board and is able to sustain high data transfer rate (1.2 GBaud). The sequencer has been modified in order to improve high–speed clocks and different reading modes. A new analogue board

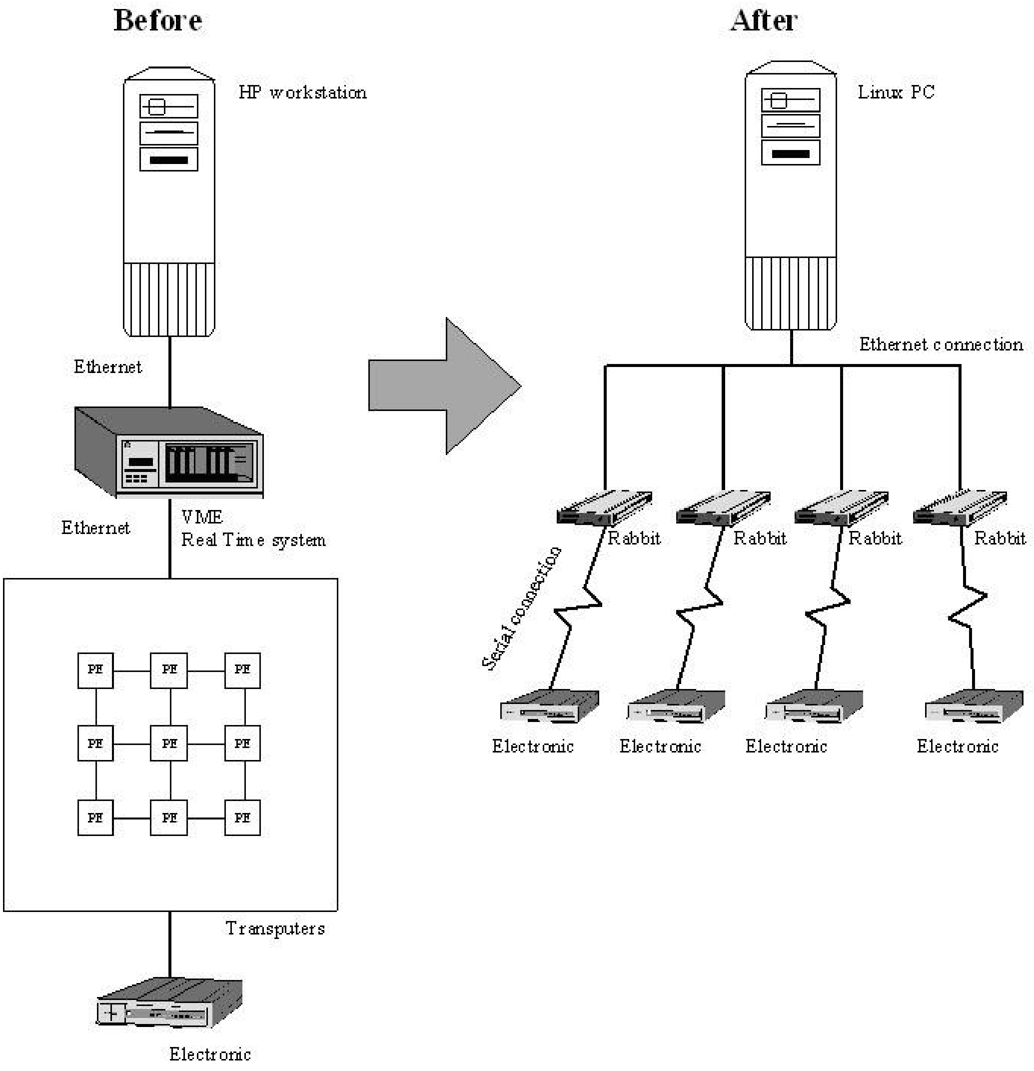

Figure 3. A diagram that shows the change introduced in the control system of the active optics of the TNG.

based on a fast A/D converter and new signal processing technique has been designed. The board is able to process four channels simultaneously allowing high acquisition rates.

The main differences consist of a change in the architecture of the system. Basically the system can be divided in two parts: the first part next to the control computer (local one), and the other one close to the detector (remote one). In the new CCD controller the preamplifier is integrated in the analogue board mounted close to the detector, and the sequence generation is located in the host computer, far from the detector. This is possible thanks to the capability of the high speed links to serialize and deserialize the sequence with a resolution of 50ns.

The analogue board is constituted by three main parts: the preamplifier, the correlated dual sampler and the bias generator. The preamplifier is based on the low noise operational Amplifier THS4061. This configuration allows 3 gain selection (G-SEL), band pass filter selection (B-SEL) and input offset programmability. The Signal Processing is carried out by using the Correlated Dual Sampling (CDS) technique (single sampling is also allowed). The output offset can be adjusted through a 14-bit D/A Converter and the A/D Converter is the LTC1608 that has 16 bits of resolution and a conversion time of 2μs. In summary, the analogue board allows: 3 selectable input gains and 3 selectable bandwidths to work at different readout speeds, the possibility to program

Figure 4. A picture of the new CCD controller, the analog and digital boards can be seen.

the offsets before and after the CDS stage, to adapt the signal to the A/D converter and the choice of different references for the dummy input. Finally the bias generator allows 16 programmable bias voltages with different ranges, divided into 4 groups. The voltage ranges are: from 15V to 30V, from 5V to 15V, from -5V to 5V and from -10V to 10V.

6. CONCLUSIONS

The control and correction of the shape of the primary mirror and the alignment with the secondary mirror are of great importance for keeping the telescope at its optimum configuration and the throughput at its maximum. The active optics system of the TNG has shown to be robust and trustworthy but some changes were needed both from the optical and from the control system point of view. Definetively it is fundamental to be able to control the overall alignment when off–axis. For this reason we have changed the support system of the pick–up mirror in the derotator, allowing for tilt correction capabilities. The control system electronics and software had to be changed because their lifetime was approaching the end and, to give continuity to the maintenance and support of the telescope, we had to move fast to widely spread software languages and standard control electronics.

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