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NAOS Real-Time Computer for Optimized Closed Loop and On-Line Performance Estimation.

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Abstract. The Real Time Computer (RTC) is a key component of an adaptive optics system. In the Nasmyth Adaptive Optics System (NAOS) for the ESO VLT, the RTC will control the 185 actuators of the corrective optics from the 144 wavefront sensor subapertures at a maximum frequency of 500 Hz. The RTC hardware architecture is fully reconfigurable to switch between the two NAOS wavefront sensors. The software includes an on-line control optimization allowing the use in a broad magnitude range (up to $M_v = 18$). This RTC is designed to be easily upgraded for Laser Guide Star.

1. Introduction

NAOS is a VLT instrument (Rousset et al. 1998) doing real-time compensation of the atmospheric turbulence using a deformable mirror and a tip-tilt mirror. The RTC is a key component controlling the 185 actuators from a 144 Shack-Hartmann wavefront sensor subapertures at a maximum frequency of 500 Hz. It also provides additional capabilities such as real time optimization of the control loop which is the warranty for NAOS to achieve a very good Strehl Ratio in a broad magnitude range ($M_v = 8$ up to 18), on-line turbulence and performance estimations and finally capability to store and process the data necessary to the off-line PSF reconstruction algorithm.

In this paper, we recall first the RTC specifications, then we present the hardware design based on SHAKTI boards and the associated maintenance concept. The software programming scheme is described and the different functionalities are associated to overall optimization of the adaptive optics system, performance estimation and off-line PSF reconstruction. Finally, we show how the RTC is designed to be easily upgraded for Laser Guide Star (LGS).

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2. RTC Specifications

The RTC is fed by images of the Shack-Hartmann spots and is dedicated to the control of the corrective optics. RTC functions are correction of detector inhomogeneities, display of the corrected image and then computation of the centroid coordinates in predefined zones. From these coordinates, the RTC computes the commands to be applied to the actuators by means of a matrix-vector multiplication. The RTC has to ensure a control-loop time-lag smaller than 200 μs. In NAOS, two wavefront sensors are used, one dedicated to visible range and the other to infrared range, each of them having several read-out modes. For this reason, the RTC has to be fully programmable. Moreover, the RTC performs pre-reductions on the various measurements. They are:

- Open-loop Zernike reconstruction on 2048 records and autocorrelation,
- Slopes and voltages expansion on modal basis for on-line optimization,
- Covariance calculation at 50 Hz for off-line PSF reconstruction,
- Real-time acquisitions of slopes, intensities, voltages and modes.

For on-line optimization the different RTC tables used during data processing must be modified in real time, i.e. without opening the loop.

3. SHAKTI Boards Concept

The SHAKTI boards have been specifically designed for Adaptive Optics (AO) and the RTC is based on a set of four. These boards are linked together by a private video bus for the real-time transfer of the computed data. This bus allows to realize parallel and/or serial architecture. Consequently, it is possible to add computing power without any modification in the architecture. It is also possible for several boards to emit data towards the same multiplexed bus. This functionality can be implemented for a multi-output CCD, where one wavefront calculation board per output can be used, or for a multi wavefront sensor system such as in Laser Guide Star.

The SHAKTI boards are based on a modular architecture. Each board is composed of a motherboard which can incorporate up to 4 modules among the following:

- Acquisition/equalization module,
- Graphic display module,
- Computation module,
- 64 channels Digital to Analog conversion module.

The motherboard allows transfers between the CPU board of the VME bus and the 4 modules. It is also in charge of extracting the data from the front panel real-time bus. The format of this video bus is chosen dynamically when loading the programmable logic components. Such a programmable hardware offers a great flexibility and would enable the use of a curvature WFS, for instance.

The equalization/acquisition module is in charge of the flat-fielding correction and is able to grab an image before or after the equalization process. The graphic module displays the image on a monitor. The computation module is based on three Texas Instruments DSP TMS320C40 hereafter called C40. Finally the DAC module is based on 64 channels 12 bits voltage output converters and is accessible directly by the VME bus and also by C40 communication link.

4. RTC Hardware Design

Data coming from the IR or VIS WFS are transferred to the equalization module of the WaveFront Power Control Board (WF-PCB) through an interface board. The WF-PCB is a mother board equipped with one equalization/acquisition module, one graphic module and two DSP Computation modules. After equalization, the data are sent to the computation module of the same board. The data are shared between two processors which compute the centroids, then the last processor computes the slopes and re-emit the data to both Control Command boards (CC-PCB).

The CC-PCB is based on a mother board equipped with two computation modules and two Digital to Analog Conversion modules. This means 300 Mflops computing power and 128 DAC outputs for each board. The whole set of CC-PCB input data are transmitted to the two first C40 of the two modules. The first one computes a part of the command and the second one a part of the slope expansion on the Zernike basis. When the computation is completed, the two C40 send the results to the third processor. This C40 performs the temporal filtering, drives the actuators through a DAC module and then sends all the computation results to the Statistical board (SC-PCB).

The SC-PCB is identical to the two CC-PCB ones but without DAC module. The two computation modules perform voltage expansion on Zernike basis, Zernike autocorrelation, slope and voltage expansion on modal basis, covariance calculation, and also perform real-time acquisitions of the different type of data.

It's important to notice that none of the pieces of information that are necessary to the servo-loop use the VME bus. This one is only used to drive the different real time boards and to read data for a later off-line reduction.

The CPU board is a PowerPC board which read communicates with the WorkStation and performs the different functionalities described in Section 5. We include on RTC a monitoring system which allow to validate the different RTC real time functionalities in closed loop mode.

5. Software Design Description

Software has been organized in independent layers in order to limit to the maximum the adaptations during an hardware or Software evolution. All these layers are written in C language and only the interfaces are dependent on ESO tools. The PowerPC board is controlled from workstation by a C++ software (Zins et al. 2000) which is entirely based on ESO basic libraries and Graphical User Interface developed in Tcl/Tk. All interactions with SHAKTI boards are controlled by one VxWorks task which has many different clients running on CPU board:

- Tip/tilt off-loading: when the loop is closed, so as to off-load the tip/tilt and focus correction, NAOS uses the telescope to compensate for the very low frequency pointing and focus errors. These errors are determined from the SC-PCB data and they correspond to average correction values.
- Sky background follow-up and threshold optimization: measurement of the sky level on the WFS camera and threshold optimization is done on average non-equalized images which are recorded without opening the loop.

- Turbulence and performance estimation: measurement of turbulence conditions is performed on 2048 consecutive records at WFS acquisition frequency every 30 seconds. The calculation is done on the 36 first Zernike by recovering the open loop data. In this way, it is possible to determine the noise level on the WFS, the turbulence correlation time at 50%, the Fried diameter R0 and the outer-scale L0.
- Closed loop modal optimization: the PowerPC board acquire the result of slopes and voltages projection on a modal basis done directly on the SHAKTI boards. After application of an algorithm to reconstruct data in open-loop, FFT is calculated and an optimal gain is determined for each mode. Then the new command matrix is computed, loaded on the RTC boards and applied without disturbing the loop. The duration of one full iteration is smaller than 3 minutes.

6. Laser Guide Star (LGS) Upgrade

Adding a LGS requires that the RTC can fulfill the following functionalities:

- Get the turbulent tip-tilt signal measured on a natural guide star,
- Send LGS tip-tilt extracted from VISWFS to the LGS/fast steering mirror,
- Compute the average defocus and send the result to the LGS system.

In order to do these, another additional SHAKTI motherboard with one C40 module allows to receive a digital signal. This signal can be either the straight values of tip-tilt, or measurements of a curvature (or Shack-Hartmann) wave front sensor. The tip-tilt signals are then sent to the CC-PCB. The numerical output SHAKTI bus is used in order to send the LGS tip-tilt at a high-frequency. The value of the defocus is derived from the data computed on the SC-PCB and sent through the VLT Software communication tools.

7. Conclusion and Perspectives

Final design of NAOS RTC has been accepted by ESO in March 1999. Software development will be completed by the end of 1999. Then, the computer will be validated by using the ONERA adaptive optics bench before being integrated in NAOS in March. It will thus be available for observations to be carried out by the end of 2000. RTC hardware has been designed to answer many requirements in real-time signal processing and could be easily upgraded for LGS. Software represents the work of more than 10 man years. It contains experience gained in the Adaptive Optics field during ten years by the laboratories involved in the NAOS development. It has been developed in a very modular way so to be reusable within other frameworks.

References

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