

7.7 AO Real-Time Control Functional Requirements

The AO real time control (RTC) system provides the main system for correction of atmospherically distorted wavefronts. It is also responsible for the calibration and test of the AO system, (in coordination with higher level control functions). The AO non real-time control system (see section 7.8) provides the high level supervisory control of the RTC.

The RTC is responsible for estimation of the wavefront correction to be applied to the correction elements (deformable and tip tilt stages) in the:

- Main AO relay
- High Strehl AO relay (2nd stage of the cascade)
- The LOWFS to sharpen the tip tilt stars
- Each d-NIRI channel for science observations

In its primary mode, when used with laser guider stars, the RTC analyzes the LGS wavefront from 9 laser beacons. In addition, inputs from three NGS wavefront sensors will be used to estimate tilt and other low order aberrations such as focus and astigmatism. The totality of these wavefront sensor inputs is used to estimate the three dimensional volume of atmospheric turbulence over the telescope. This estimation step is commonly called “tomography” in analogy with medical x-ray imaging techniques. The RTC is responsible for using the tomographic solution to determine the shape applied to the various deformable mirrors in the AO system. The RTC also receives input on the difference between LGS and NGS measurement of atmospheric turbulence from a NGS truth wavefront sensor (TWFS). Additionally, the RTC will support a NGS mode (no LGS) where natural guider stars will provide all the wavefront information.

The RTC will interface to the other observatory and AO systems including, telescope drive control system (DCS), the laser guider star facility, and the wavefront sensor positioning mechanisms. The RTC will update and optimize its control algorithms as conditions change. The RTC will report status information to the AO sequencer. It will also log input and output quantities for AO and scientific data analysis. The RTC will provide built-in diagnostics and be fully operable and maintainable by observatory staff.

This document is largely implementation free. Useful information about the RTC may be found in the original reference design for the NGAO real-time control system detailed in Appendix 12, section 5 of the NGAO proposal June 2006 see:

http://www.oir.caltech.edu/twiki_oir/pub/Keck/NGAO/WebHome/NGAO_Proposal_Final.pdf

It is also archived as Keck Adaptive Optics Note (KAON) 400

DRAFT 9/11/2007

7.7.1 Architectural Assumptions and Overall Requirements

RTC latency and AO system bandwidth:

The AO system 0 db closed-loop error cutoff frequency in LGS mode will be 54.3 Hz. (This number is defined at 54.3 Hz in the NGAO wavefront error spreadsheet v1.26.)

The following values are **not** requirements but an example allocation to guide the designer. The delays from WFS exposure time, WFS readout, all RTC computations and updating the deformable mirrors, must be consistent with the overall AO bandwidth specification given above. Typical control techniques would require an update rate of 1 KHz. This would allow an exposure time of 400 micro seconds, a readout time of 500 micro seconds, compute latency 250 micron seconds and 50 micro seconds to update the deformable mirrors.

The RTR end to end processing latency is TBD

Numerical Precision

The RTC numerical precision including digitization of the drive signals sent to the deformable mirrors must be consistent with a final wavefront error of 1 nm rms. (Typically this error is not a large factor in RTC design but is included because it is explicitly called out in the wavefront error spreadsheet version 1.26)

The following is a list of architectural assumptions for the RTC system:

LGS WFS Processing (LGS AO)

- a) The RTC will input WFS pixels from multiple LGS sensors and calibrate them for sensor and sky backgrounds. Includes provisions for subtraction of Rayleigh background if CW sodium lasers are used.*
- b) The RTR will estimate wavefront slopes from WFS pixel intensities using TBD algorithm or algorithms.*
- c) The RTR will update its estimate algorithm of the wavefront slopes as atmospheric and sodium layer conditions change.*
- d) The RTC will estimate the full aperture tip tilt from each LGS wavefront and export this information to the appropriate subsystem for LGS tip tilt control, also know as uplink tip tilt. (This subsystem could be located at either LGS launch telescope or input to each LGS WFS channel, this is TDB). Specific rate is TBD.*
- e) If the selected laser is pulsed, to reduce background form Rayleigh scattering, the LGS WFS CCD should be synchronized with laser pulse rate. The timing error and clock source are TBD at this time.*
- f) The RTC shall allow adjustable frame rates for LGS observations.*

DRAFT 9/11/2007

Table 1: Summary of wavefront sensors and correctors for NGAO RTC

LGS WFS	LOWFS	NGS	Truth Sensor	Main Relay	Second Relay	MOAO
9 total wavefront sensors: 5 in ring 1 at center 3 located next to NGS used in LOWFS	2 Tip Tilt only, 1 Tip Tilt, focus, and astigmatism sensor	One	Low order low speed	Woofers or ground layer control	Tweeter control	1 DM each in LOWFS 1 DM each d-NIRI channel
589 nm	IR	Visible or IR (TBD)	Visible or IR (TBD)			
				Optional 2 nd mirror in main relay for MCAO mode		
64 subapertures across pupil	Full aperture and/or 2x2 subapertures	64 subapertures across pupil	6x6	20 actuators across pupil	64 actuators across pupil	32 across pupil LOWFS 64 across pupil d-NIRI

Low-order wave front sensor (LOWFS) high-bandwidth NGS processing (LGS AO mode)

- a) *The RTC will input WFS pixels from multiple low order NGS and calibrate them for sensor and sky backgrounds.*
- b) *The RTR will estimate wavefront slopes from pixel intensities using TBD algorithm or algorithms.*
- c) *The RTR will update its estimate of the wavefront slopes as atmospheric conditions and AO performance change. RTR will optimize the setting of the NGS WFS based on NGS star brightness, atmospheric conditions, and AO performance.*

DRAFT 9/11/2007

- d) RTC will adjust frame rates of the tip tilt sensors between 10-TDB Hz as the brightness of the NGS changes. The rate of each LOWFS sensor will be independently selectable.*

High-order NGS WFS Processing NGS (NGS AO):

- a) The RTC will input WFS pixels from single NGS and calibrate them for sensor and sky backgrounds.*
- b) The RTR will estimate wavefront slopes from CCD pixel intensities using TBD algorithm or algorithms.*
- c) Update slope estimation algorithm for seeing and AO performance at a TBD rate.*
- d) Adjust frame rate of wavefront sensor between 1-2000 Hz as NGS guide star brightness varies.*

Truth WFS Processing (TWFS):

- a) Calibrate slow variations and biases in AO control from changes in sodium layer profile, flexures, and drifts. At this time, the expected update rate of the Truth wavefront sensor maybe slow enough that the information could be processed by either an RTC subsystem or a dedicated TWFS server that would perform wavefront reconstruction on the TWFS input and not the RTR. For the purposes of this document, we assume that the TWFS server performs the reconstruction. Details for the TWFS server are included in section 7.8 non real time control.*
- b) The TWSF server will provide low order NGS wavefront information*
- c) The focus information from the TWFS will be used to change the focus of the LGS wavefront sensors.*

Wavefront Reconstruction:

- a) In LGS mode the RTC will take wavefront gradient information from LGS WFS, the LOWFS to make a tomographic estimate of the atmospheric turbulence above the telescope using a TBD algorithm.*
- b) In LGS mode, the RTC will estimate the proper correction to apply to the various correcting elements in the system (see Table 1) based on the tomographic solution in the step a) above.*
- c) The RTC will be able to initialize the wavefront reconstruction algorithm using information about the LGS constellation, the NGS constellation for the LOWFS, the science mode and instrument, the atmospheric turbulence profile, wavefront*

DRAFT 9/11/2007

sensor signal levels, the orientation of the telescope pupil, the orientation between wavefront sensor measurements, and AO deformable mirror actuators.

- d) In NGS mode, the RTC will estimate the wavefront from a bright NGS guide star and optionally use wavefront information from other NGS in the field that are measured by the LOWFS.*

Temporal Filtering :

- a) The RTC will temporally filter the wavefront estimate from the LGS WFS, LOWFS, and the TWFS to achieve stability and optimal correction of the wavefront. The RTC will perform analogous function for NGS mode observations.*
- b) The RTC will temporally filter the correction between first stage and second stage mirrors in the main cascade relay for optimal performance.*
- c) The RTC will temporally filter the correction between the main deformable and the deformable mirrors inside the LOWFS channels and the d-NIRI science channels.*

RTC control functions:

- a) The RTC will offload focus from the AO system to the telescope secondary.*
- b) The RTC will offload tip tilt errors to telescope elevation and azimuth drive control system*
- c) The RTC will filter the build up of un-sensed modes, such as piston and global waffle.*
- d) The RTC will compute commands for deformable mirror actuators that fall outside the illuminated foot print of the deformable mirror, i.e. slaved actuator commands.*
- e) If needed the RTC will provide functionality for determining the shape of the common deformable mirror in the first stage of the cascaded relay. Alternatively some means of monitoring the shape of the first stage deformable mirror directly will be provided (for instance a high speed interferometer).*

Data Acquisition:

- a) The RTC will provide high speed data to support AO engineering tasks (this is sometimes referred to as telemetry data).*
- b) The RTC will provide high speed data to support PSF reconstruction.*

Wavefront corrector and WFS calibration:

- a) *The RTC will be capable of calibrating the deformable mirror act gains. The RTC will be capable of calibrating the WFS linearity. The RTC will also be capable of measuring the deformable mirror to wavefront sensor registration. Additionally, the RTC will be capable of determining the pupil orientation and illumination of various correctors and wavefront sensors in the NGAO system.*

7.7.2 Optical Requirements

This subsystem had no optical requirements.

7.7.3 Mechanical Requirements

Detailed mechanical requirements have not been determined at this time.

7.7.4 Electronic/Electrical Requirements

Detailed electrical requirements have not been determined at this time.

7.7.5 Safety Requirements

No safety requirements have been determined at this time.

7.7.6 Software Requirements

Detailed software requirements have not been determined at this time.

7.7.7 Interface Requirements

The RTC will interface with the Adaptive Optics non real-time control system as a means of high level control and coordination functions for the NGAO system.

The RTC will interface with an observatory data system for storage of AO telemetry data for AO engineering and science data analysis (i.e. PSF estimation, data quality assessment, and other TBD tasks).

The RTC will interface with the telescope control system. The RTC will offload focus to the telescope secondary. The RTC will offload tip and tilt errors back to the telescope azimuth and elevation drives. The RTC will get information on the telescope pointing and pupil rotation to assist in wavefront reconstruction tasks.

The RTC will interface with the laser guider star facility in order to support the acquisition of each LGS on its intended wavefront sensor. In addition the RTC will send

DRAFT 9/11/2007

the average full aperture tip and tilt of each LGS to the Laser control software for stabilization of the LGS on the sodium layer.

RTC will have an electrical interface with the AO deformable mirror and tip tilt correctors listed in table 1.

The RTC will interface with the detectors used in the LGS WFS, the LOWFS, and the NGS wavefront sensor. The RTC will read pixel intensities from these devices. The RTC will be able to control the readouts rates and other TBD characteristics of these devices.

The RTC will interface with the truth wavefront sensor (TWFS) server. The RTC will receive information about the NGS wavefront in order to correct for structure in the sodium layer and elongation of the LGS.

RTC will interface with the AO non real-time control system in order to control the focus of the LGS wavefront sensors, aberration correction optics in the LGS wavefront sensor, the pickoffs for the various wavefront sensors in the NGAO system these include the LGS, NGS, and LOWFS.

RTC will interface to the d-NIRI instrument in order to estimate the turbulence correction on a light of sight through the atmosphere that corresponds to the desired science object

7.7.8 Reliability Requirements

The RTC shall be designed to minimize downtime.

The RTC will provide built-in diagnostics and be fully operable and maintainable by observatory staff.

The system shall be designed for operation on a TBD basis.

The system shall be designed to be deployed at night with TBD hours of preparation for setup and calibration, so that it can support both classical and semi queue scheduled modes.

Setup and preparation times:

Daytime prep time TBD

Nighttime setup time TBD

Object setup TBD

Scalability and Upgrades

These requirements are TBD

7.7.9 Spares Requirements

TBD pending results of failure analysis of system.

DRAFT 9/11/2007

7.7.10 Service and Maintenance Requirement

TBD pending results of failure analysis of system.

7.7.11 Documentation

Standard documentation provided including:

Mechanical drawings

Electrical schematics

Software documentation