CALTECH OPTICAL OBSERVATORIES / NASA JET PROPULSION LABORATORY
PALM-3000 PROJECT

PALM-3000
Instrument Architecture Document (IAD)

CIN #629

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Revision Sheet

Release No.	Date	Revision Description
Rev. 0.1	7/18/07	Initial rough draft by A. Bouchez
Rev. 0.2	10/23/07	Added laser facility, safety systems. A. Bouchez
Rev. 0.3	11/11/07	Added electronics and software. A. Bouchez

Contents

1 GENERAL INFORMATION

1.1 Purpose

The instrument architecture document (IAD) presents the current conceptual design of the PALM-3000 adaptive optics system, allowing detailed performance modeling and systems engineering trades to be performed with a consistent set of architectural assumptions.

1.2 Scope

This IAD describes the high-level conceptual design of the PALM-3000 instrument, including instrument layout, the functions of and interfaces between subsystems, and operating modes. The software architecture is only addressed here at a cursory level, and will be described in greater detail in a separate Software Architecture Document (SwAD). Detailed descriptions of subsystems and their interfaces will be given in the System Design Manual (SDM).

1.3 Acronyms and Abbreviations

AO	Adaptive optics
CCD	Charge coupled device detector
CSFL	Chicago sum-frequency laser
DM	Deformable mirror
FSM	Fast steering mirror
GPU	Graphics processing unit
HOWFS	High-order wavefront sensor
IRTT	Infrared tip/tilt wavefront sensor
LLT	Laser launch telescope
LOWFS	Low-order wavefront sensor
LGS	Laser guide star
MASS	Multi-aperture scintillation sensor
NGS	Natural guide star
PALM-3000	A 3000+ actuator upgrade to the Palomar AO system
PC	Personal computer
TWFS	Truth wavefront sensor
UTTM	Uplink tip/tilt mirror

1.4 Inputs

- P3K Science Requirements Document (SRD, CIN #612), R. Dekany
- P3K Instrument Interface Control Document (IICD, CIN #603), A. Moore
- P3K Observing Scenarios Document (OSD, CIN #623), A. Bouchez
- P3K Instrument Requirements Document (IRD, CIN #624), R. Dekany
- P3K IRTT Dichroic Optimization (CIN #620), R. Dekany

1.5 Related Documents

- P3K Error Budget Summary (EBS, CIN#626), R. Dekany
- P3K Telescope Interface Control Document; TBD
- P3K System Design Manual, J. Roberts.

    - Note: many of the subsystem interfaces will be captured in the SDM, as opposed to a multitudinous collection of subsystem ICD's.
- P3K Observer's Manual, A. Bouchez.
- P3K TWiki Pages at: http://www.oir.caltech.edu/twiki_oir/bin/view.cgi/Palomar/Palm3000/WebHome
- P3K Stimulus Requirements Document; J. Roberts
- P3K Enclosure Requirements Document; TBD
- P3K DM3326 Requirements Document; M. Troy
- P3K HOWFS Requirements Document; TBD
- P3K LOWFS Requirements Document; TBD
- P3K TWFS Requirements Document; TBD
- P3K IRTT Requirements Document; TBD
- P3K Supervisory Control Requirements Document; TBD
- P3K RTC Requirements Document; TBD
- P3K LGSF Requirements Document; TBD
- P3K Operations Requirements Document; TBD
- P3K Commissioning Plan; TBD
- P3K Infrastructure Requirements Document; D. McKenna (TBC)

1.6 Point of Contact

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INSTRUMENT CONCEPT

1.7 Reuse of PALMAO components

To reduce cost and schedule, PALM-3000 will make maximum use of current PALMAO hardware and software. In particular, the following components will be reused with little or no alteration:

- AO cart (used to transport the AO system)
- AO spit (used to support the AO system during lab work)
- AO optical bench and Cassegrain interface support structure.
- Relay optics: eg. Off-axis parabolas (OAP), fast steering mirror (FSM), fold mirrors.
- 349-actuator Xinetics deformable mirror (DM349).
- Low-Order Wavefront Sensor (LOWFS), as an interim tip/tilt/focus sensor.

1.8 Project phases

To address a shortfall in available resources, we are developing PALM-3000 in two phases, delaying the second phase until sufficient funding can be identified. A preliminary phase consisting of the re-layout of the PALMAO relay optics, necessary for compatibility with the SWIFT and Project 1640 instruments, is not covered here in detail. Phase 1 will consist of the development and integration of the 3326-actuator deformable mirror (DM3326), a new high-order wavefront sensor, and wavefront processor system. Phase 2 will include the addition of an infrared tip/tilt sensor (IRTT) and the replacement of the current low-order wavefront sensor (LOWFS) with a truth wavefront sensor (TWFS). The evolution of the instrument architecture through the phases of the project will be identified below.

1.9 Instruments and observing modes

PALM-3000 will support both visible and near-infrared instruments, using either NGS and LGS guide stars, leading to four observing modes: NGSV, LGSV, NGSIR and LGSIR. All instruments will be located at the current location of PHARO, and can span the entire width of the AO bench with a maximum footprint of 18 by 54 inches. Instruments shall be mounted either to a set of 4 fixed mounting points near the corners of this space, or to the optical bench between them. Instrument changes will be performed only in daytime, and thus instrument-specific optics (eg. dichroics or fold mirrors) housed in kinematic cells or mounts can be manually changed out at that time.

2 OPTICAL LAYOUT

2.1 Stimulus unit

The stimulus unit will provide calibration sources for all AO modes. These include simultaneous broadband (NGS) and narrow-band ~589 nm (LGS) sources, and a bright laser source for optical alignment. The stimulus unit will be located on the upper (telescope) side of the optical bench, and will be coupled onto the optical axis of the Hale Telescope, just upstream of the telescope focus, using a fold mirror mounted on a motorized stage.

2.2 AO relay

The PALM-3000 AO relay will consist of a single pair of off-axis parabolic mirrors, a fast steering mirror, two deformable mirrors (DM349 and DM3326), and a fold mirror, all located on the lower side of the optical bench. Both deformable mirrors will reside within 1.5 km of the ground conjugate, with the exact conjugation remaining to be determined.

2.3 Wavefront sensors beam splitting

The wavefront sensor splitting will follow a branching layout, as illustrated in Figure 1, with two fixed beamsplitters in the converging beam downstream of OAP2. Splitter #1 will direct infrared light in the J and H bands to the IRTTS (phase 2 only). Splitter #2 will direct light to the visible wavefront sensors. This beam will then be further divided between the HOWFS and LOWFS or TWFS (in LGS modes only) by splitter #3. The IRTT will not patrol, as its instantaneous field of view is sufficient to encompass the required 90" radius patrol range. The patrol mechanisms for the HOWFS and LOWFS/TWFS have yet to be determined, but are sketched as steering mirrors in Figure 1. The requirement to rapidly change from LGS to NGS modes for a given science instrument (P3K-SCI-REQ-0025) will be met by mounting beamsplitter #3 on a motorized stage.

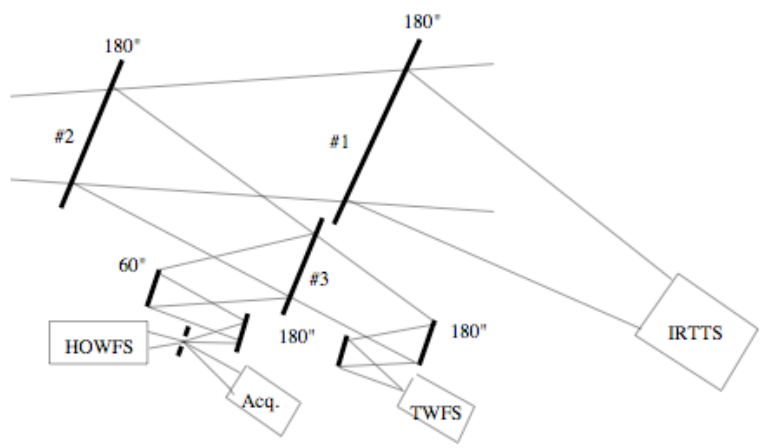

Figure 1: Schematic of the PALM-3000 wavefront sensor layout in Phase 2. Beamsplitters are numbered as in Table 1, with the field of view in arcseconds passed by each optic noted.

AO Mode	Beam splitter			Comments
	#1	#2	#3	
NGS-IR	open	970 LP	open	
LGS-IR	30% 1100-1780 R	970 LP	589 NR	
NGS-IR from LGS-IR	30% 1100-1780 R	970 LP	open	30% loss in sensitivity in J and H.
NGS-V	open	50% R or 650 LP	open	#2 choice depends on science band.
LGS-V	1000-1780 R	595 LP	589 NR	No science at <595 nm.
NGS-V from LGS-V	1000-1780 R	595 LP	open	No science at <595 nm.

Table 1: Brief description of wavefront sensor beamsplitters which will be used to support the 4 observing modes described in the SRD, Table 7. While rapid changes from LGS to NGS mode for a given instrument will be supported, some compromise in performance is incurred relative to dedicated NGS observations. These backup NGS modes are indicated as "from LGS".

3 WAVEFRONT SENSORS

3.1 High-order wavefront sensor

A single Shack-Hartmann high-order wavefront sensor (HOWFS) will sense both NGS and LGS wavefronts. It will provide 4 selectable pupil samplings: 8x8, 16x16, 32x32, and 64x64 subapertures across the Hale Telescope pupil, and will use the SciMeasure Lil' Joe chassis and a E2V CCD50 128x128 pixel detector. An adjustable field stop will allow both spatial filtering, and the optimization of the sensor field of view when using an extended laser guidestar. The wavefront sensor will be fully enclosed to reduce off-axis scattered light, and will ride on a focus stage with sufficient travel to reach a near focus of 80 km.

3.2 Infrared Tip/Tilt Sensor

The Phase 2 infrared tip/tilt sensor (IRTT) will be a direct imaging camera using a HAWAII2-RG detector with region-of-interest readout capabilities, sensitive to the J and H bands (1100-1780nm). It will be housed in a liquid nitrogen cooled Dewar near the present location of the HOWFS (see Figure 1). The IRTT field of view will be sufficient to allow access to the required guide star patrol range (180" diameter) without the need for field or sensor translation. Rather than reimaging a pupil, the IRTT will use a cold "snout" and an IR-blocking filter with a cutoff wavelength of 1.78 µm to control the thermal background at the detector.

The IRTT will be used in either an acquisition or tip/tilt control mode. In acquisition mode, a full-field integration will be read out and displayed to the user interface for guidestar selection. Upon selecting the guide star, a single quad cell of 4 pixels will be read out at up to 500 Hz to provide the tip/tilt control signal for LGS observing modes.

3.3 Low order wavefront sensor

The PALM-LGS low order wavefront sensor (LOWFS) will be used for low-order wavefront control (tip/tilt/focus) in LGS observing modes through phase 1 of the PALM-3000 project. It is a 3x3 Shack-Hartmann wavefront sensor based on a SciMeasure Lil'Joe camera with a CCD39 detector. We intend to improve the cooling of this camera in Phase 1 to modestly improve its performance over present levels. It patrols the focal plane on a 2-axis translation stage.

3.4 Truth wavefront sensor

The truth wavefront sensor (TWFS) will be a Shack-Hartmann sensor with 2x2 pupil sampling, which will replace the 3x3 LOWFS in Phase 2 of the PALM-3000 project. As with the LOWFS, it will utilize a SciMeasure Lil'Joe camera with a CCD39 detector. However, smaller binned pixels and fewer subapertures should lead to a significant increase in sensitivity. The TWFS will primarily be used to sense only focus, but will provide a backup tip/tilt capability in case failure of the IRTT (or unusually blue NGS). The focal plane patrol mechanism for the TWFS has yet to be determined.

4 ELECTRONICS

4.1 Cassegrain Cage Electronics

PALM-3000 electronics in the Cassegrain Cage will be housed in 3 full-height computer racks mounted during instrument installation. Unlike the current PALMAO racks, these will be active cooled to reduce power dissipation to the primary mirror and dome air, necessitating the installation of liquid coolant lines at the Cassegrain focus of the Hale Telescope.

The Controller Rack will house camera controllers, motor controllers, and communications hardware. The Lights and Drivers Rack will house light sources for the stimulus, and the DM349 driver electronics. A third rack will house DM3326 driver electronic.

4.2 Computer Room Electronics

The wavefront processor will be located remote to the PALM-3000 system, in the environmentally-controlled computer room on the mezzanine. While the choice of hardware has not yet been finalized, the leading candidate architecture based on NVIDIA 8800 Ultra graphics processing units (GPUs) is described here: Sixteen (16) of these processing units will be deployed in 8 PCs, each performing a portion of the full vector matrix multiplication required for high-order wavefront reconstruction (see Figure 2). An additional PC (labeled PC0 in Figure 2) will perform supervisory tasks, compile and send DM commands to the DM drivers, and perform low-order wavefront reconstruction on a single GPU. All communication between the wavefront sensor cameras and DM drivers (in the Cassegrain Cage) and wavefront processors (in the computer room) will be by optical fiber. Finally, a telemetry data server will buffer and record to a RAID disk array high-speed telemetry from the wavefront processors, making this data available for status display and performance analysis.

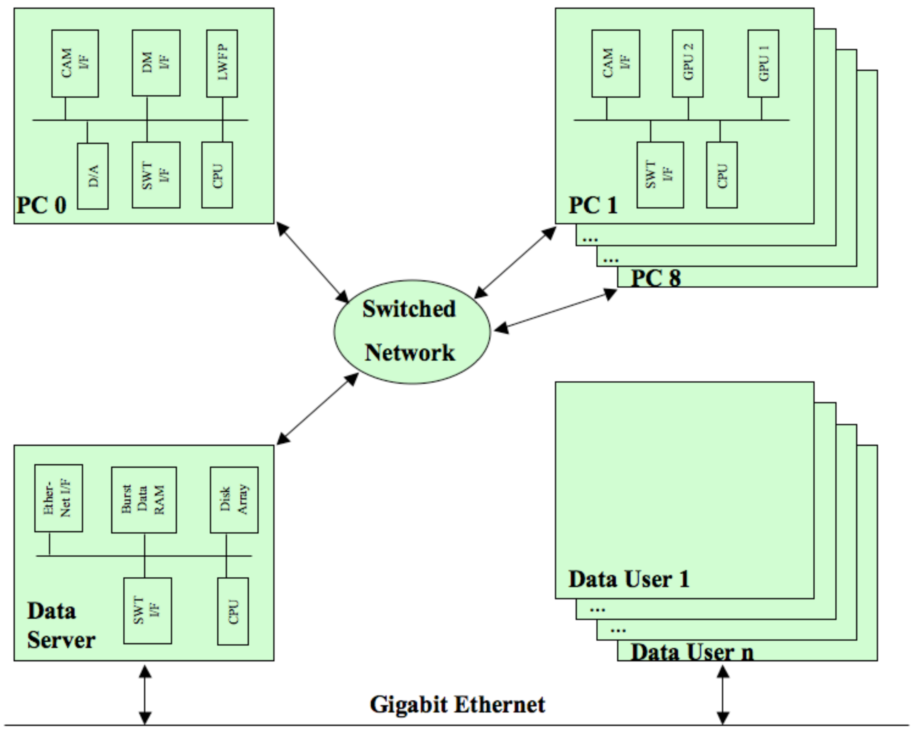

Figure 2: Proposed real-time computer architecture based on NVIDIA graphics processors.

4.3 Data Room Electronics

A workstation located in the data room will control of the observing functions of PALM-3000, and provide feedback to the operator on system status and performance.

5 SOFTWARE ARCHITECTURE

5.1 Real-time software

The real-time software will reconstruct the residual high- and low-order wavefront, decomposing this wavefront into commands to the FSM, UTTM, DM349, and DM3326. The PALM-3000 software will allow either of two alternate methods for commanding DM349 to be used, as illustrated in Figure 3. Either the low-order modes present on the tweeter DM3326 will be offloaded to the woofer DM349 in an outer control loop, or both sets of actuator commands will be reconstructed simultaneously via matrix multiplication.

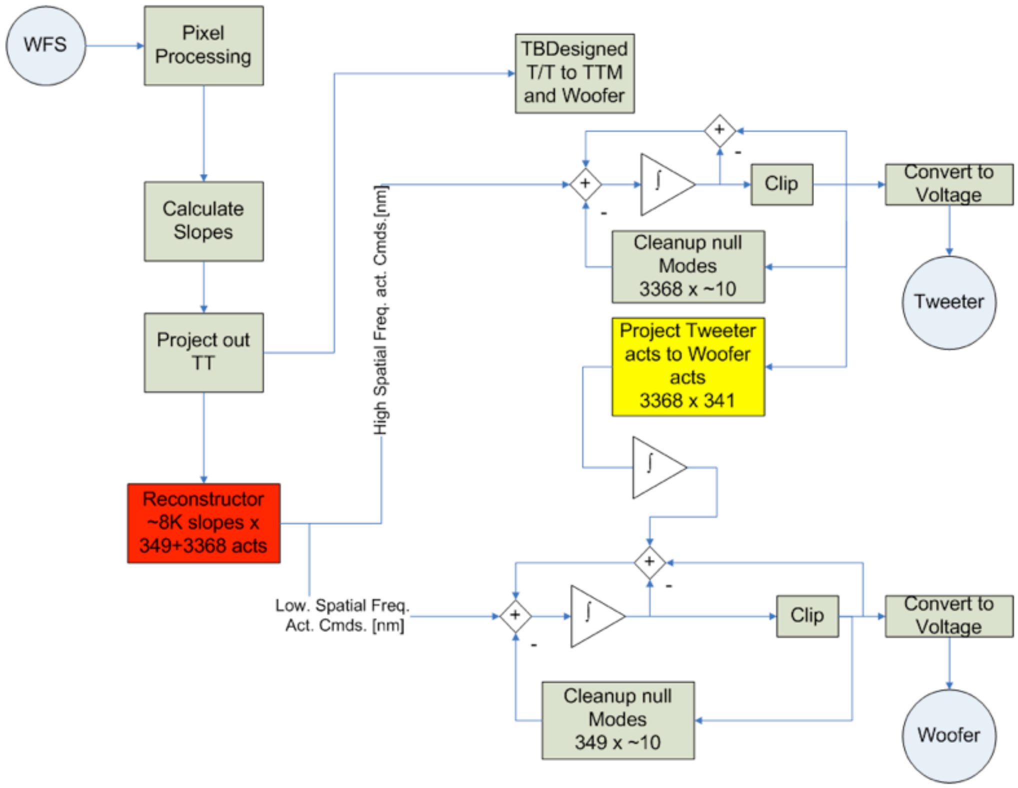

Figure 3: Wavefront processor block diagram, illustrating two pathways for controlling woofer DM349. Both will be implemented in PALM-3000.

5.2 Supervisory control software

The supervisory control system will control the interactions between the user interface, wavefront processors, telemetry system, and motor controllers. In addition, it will provide system status data to the user interface and telemetry system.

5.3 Operational systems software

Operational systems software includes a graphical user interface to PALM-3000, system performance displays, and all high-level automation function required to achieve the science requirements. The graphical user interface will both display the system status, and allow the operator to adjust basic system parameters such as the many servo loops, motor positions, telemetry recording, etc. Performance displays will include live displays of wavefront sensor pixels and DM commands, and strip-charts displaying the time-history of each servo loop's performance. Higher-level automation functions provided by the user interface will include:

- Guide star acquisition on all wavefront sensors
- Wavefront sensor background recording
- Wavefront sensor to DM registration
- Flexure and atmospheric refraction compensation
- Phase-diversity measurement of the static aberrations seen by the science instrument
- Optimization of the LGS reconstructor using Palomar MASS C_n^2 data

6 LASER GUIDESTAR FACILITY

6.1 Lasers

In LGS observing modes, PALM-3000 will initially use the Chicago Sum-Frequency Laser (CSFL), in science operation at Palomar Observatory since April 2007, to generate an artificial guide star. The CSFL will be located in the lower Coude lab, directly below its present location in the upper Coude lab. The lab will include space and utilities to accommodate as second laser, should one become available.

6.2 Beam transfer and launch system

The beam transfer system will format and direct laser light from the lower Coude lab to the launch telescope, located behind the Hale telescope secondary mirror. It will utilizes free-space propagation, with 8 mirrors and 7 transmissive optics between the laser bench and the launch telescope focus. Three of the mirrors are actively controlled to compensate for flexure as the Hale telescope tracks the sky. Polarization optics are used to maximize the transmission of the system and convert the outgoing beam to circular polarization.

The laser launch telescope (LLT) is a catadioptric design with a 0.46 m diameter and small (38mm) obscuration, located on the optical axis of the Hale telescope and mounted during LGS-AO observing runs to the flange typically used to mount prime focus instruments.

6.3 Laser safety

Due to the significant ocular hazard of the Class 4 laser systems used to generate laser guidestars, all areas which might be subject to laser radiation are controlled by signage and interlocks which shutter the laser in case of entry. These areas include the Coude lab, Coude alleyway, and Hale Telescope dome floor and catwalk. Aircraft safety is addressed through the use of a three-tiered automated safety system (visible all-sky and narrow-field infrared cameras, and a boresight radar) and human spotters. We hope to adopt a fully automated aircraft safety system when Federal Aviation Administration approval is granted. Spacecraft safety is assured through coordination with US Space Command.