Keck Adaptive Optics Note 823

Near-Infrared Tip-Tilt Sensor System Requirements Document

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Authors:
Peter Wizinowich

Contributors:
R. Dekany, E. McGrath, M. Morris, C. Neyman, T. Stalcup, T. Treu

Document Revision History

Revision Number	Revision Date	Summary of Changes	Author
1.0	11/22/2010	SDR release	Peter Wizinowich
1.1	12/16/2010	Corrected typo in req. 2 (NGS to LGS). Added integration time to Table 1 caption. Req. 12 changed to a goal.	P. Wizinowich
1.2	3/19/2011	Changes tracked in KAON 835. Modification to requirement #9. Clarifications added to #23, 24, 25 and 30. Added #29 and 61.	P. Wizinowich
1.3	3/26/11	PDR release. Modified SR-38 & 39 (see KAON 835 change log).	P. Wizinowich

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1 Acronyms

AO	Adaptive Optics
ATI	Advanced Technologies and Instrumentation
HQ	Head Quarters
KAON	Keck Adaptive Optics Notes
LGS	Laser Guide Star
NGAO	Next Generation Adaptive Optics
NGWFC	Next Generation Wave Front Controller
NIR	Near InfraRed
NSF	National Science Foundation
OSIRIS	Oh-Suppression near InfraRed Integral field Spectrograph
STRAP	System for Tip-Tilt Removal with Avalanche Photo diodes
TBC	To Be Confirmed
TBD	To Be Determined
TTS	Tip-Tilt Sensor
WMKO	W. M. Keck Observatory

2 Introduction

This requirements document is written in support of the NSF ATI-funded near-infrared (NIR) tip-tilt sensor (TTS) project. The purpose of this document is to define the requirements for the NIR TTS system to be implemented with the Keck I LGS AO system.

These requirements are maintained in the system and functional requirements spreadsheet, KAON 835, which is a configuration controlled document. In the event of a discrepancy between this document and the spreadsheet, then the spreadsheet (KAON 835) should take precedence.

3 Science Requirements

The NSF ATI proposal for the NIR TTS identified three limitations of Keck LGS AO that this proposal was intended to alleviate:

- Improve the sky coverage for intrinsically rare science objects.
- Allow LGS AO science in heavily dust obscured regions such as star forming regions.
- Improve the astrometric precision and spatial resolution currently limited by residual tip-tilt errors.

The NSF ATI proposal provided an overview of a few key science areas that will benefit from the performance improvements provided by a NIR TTS: 1) galaxy morphology, 2) supernovae, 3) dark matter in galaxies and 4) science of dust obscured objects.

A direct flowdown from science cases was not presented in the NSF ATI proposal nor will it be provided here. The NIR TTS was chosen as a proposal since tip-tilt errors are generally the largest error terms for science with the current Keck LGS AO systems. This was demonstrated in the proposal with an error budget for the high-redshift galaxies science case (this is a NGAO key science driver). This error budget is reproduced in Table 1. It will be important that the implemented NIR TTS achieve these reductions in tip-tilt errors (bandwidth, measurement and anisoplanatism).

The system requirements must include requirements addressing the following areas that directly impact the science. The related system requirement numbers are listed in parentheses.

- Sky coverage.
    - Limiting magnitude for usable tip-tilt stars (#13, 14, 34)
    - Field of view for usable tip-tilt stars (#33)
    - Acquisition (#8, 33, 34)
- Tip-tilt residuals for short and long exposures
    - Residuals versus tip-tilt star magnitude and off-axis distance (#4)
    - Residuals versus exposure time.
        - Vibrations (#37)
        - Stability (#26)
        - Differential atmospheric refraction correction (#22)
- Wavelengths at which science can be performed with the NIR TTS (#35, 36)
- Wavelengths at which tip-tilt sensing can be performed (#13, 14, 34)
- Throughput and emissivity (#35,36)
- Field of view over which science can be performed with the NIR TTS (#15)
- Observing modes (#47)
    - Refocus (#16)
    - Dithering, nodding, offsetting (#23)
    - Non-sidereal tracking (#28, goal only)
    - Fixed pupil mode (#29)
    - Use of non-point sources (#10, 11)
- Positioning accuracy and repeatability (#24,25,27)

- Observing efficiency (#18, 20, 21)
- Higher bandwidth focus measurements (#5, goal only)
- Performance monitoring (#29)
- Observation planning (#47, 65, 66)

Error Term	High-Redshift Galaxies (r0 = 14.7 cm @ 30° zenith angle; wind 9.5 m/s)		
	K2 2009	K1 2010	K1 2013 (w/ new TTS)
Atmospheric Fitting	126	126	126
Telescope Fitting	66	66	66
Science Camera	30	30	30
DM Bandwidth	108	55	55
DM Measurement	146	71	71
Tip-tilt Bandwidth	145	145	89
Tip-tilt Measurement	191	192	95
Tip-tilt Anisoplanatism	190	190	111
LGS Focus Error	34	34	34
Focal Anisoplanatism	187	187	187
LGS High Order Error	50	50	50
Calibration Errors	29	29	29
Miscellaneous	90	36	101
Total Wavefront Error	442	405	329
Science Wavelength	2.2 μm		
Strehl Ratio	20%	26%	41%
Ensquared Energy (50 mas)	18%	23%	32%

Table 1: Keck LGS AO wavefront error budgets (in nm rms) as performance is improved: 2009 Keck II LGS AO system, predicted Keck I LGS AO system with the new laser in 2011, and the Keck I LGS AO system with a NIR TTS. The high redshift galaxies science case is assumed including 30% sky coverage, 60° galactic latitude, 30° zenith angle, median seeing conditions and an 1800 sec science integration.

4 System Requirements

4.1 Overall Requirements

1. Provide a NIR TTS system for the Keck I LGS AO system and OSIRIS.
2. The NIR TTS system shall be capable of operating as an integrated part of the Keck I LGS AO control system.
3. When the NIR TTS system is not in use it shall allow the current science modes of the AO system and science instrument to be used with no reduction in performance.
4. Provide improved tip-tilt correction and improved sky coverage for LGS AO science operations. Specifically, the NIR TTS system shall achieve the performance improvements predicted in Table 1 under the conditions indicated. The performance is allowed to degrade with respect to Table 1 as the conditions worsen.
5. Goal: Provide TBD improved focus correction and reduce the overhead for focus measurements by TBD during LGS AO science operations.
6. The NIR TTS system shall be operable, with performance consistent with system requirement #4, over a range of seeing conditions up to the 80^{th} percentile seeing. The goal is 90^{th} percentile seeing.

7. The NIR TTS system shall be operable, with performance consistent with system requirement #4, over the telescope zenith angle range from 0.5° to 65°.

8. The NIR TTS system shall come equipped with a means of identifying the location of tip-tilt stars on the camera. For example, the NIR TTS could have its own acquisition mode or the existing acquisition camera should be capable of adequately positioning stars on the NIR TTS.

9. Goal: The NIR TTS system shall be capable of using up to three tip-tilt stars as input to the real-time controller tip-tilt determination, plus a single readout area for sky background measurements.

10. The NIR TTS system shall be capable of using non-point sources ≤ 0.1" in diameter, with performance consistent with system requirement #4.

11. Goal: The NIR TTS system shall be capable of using non-point sources ≤ 1" in diameter, with performance consistent with system requirement #4.

12. Goal: The NIR TTS system shall be capable of operating in parallel with the existing visible TTS (STRAP) for improved tip-tilt correction. Both sets of data shall be capable of being used together by the real-time controller to calculate the TT to be applied to the TT mirror.

13. The NIR TTS system shall be capable of using stars as faint as K = 16 mag over its entire field of view.

14. The NIR TTS system shall be capable of using stars as faint as H = 16 mag over its entire field of view.

15. When the NIR TTS system is used the science field of view of interest shall be unvignetted. Depending on the science case the science field of view of interest may include just the OSIRIS IFU or both the IFU and imager. Options shall be provided to allow both the IFU and imager fields of view to be passed when the NIR TTS is operated in H or K-band.

16. The NIR TTS shall be positioned to be parfocal with the science instrument focal plane. This will require that the NIR TTS be able to refocus for different observing modes.

17. The time required for any routine daytime calibrations of the NIR TTS system shall not exceed 20 minutes.

18. The time required for any routine nighttime start of night calibrations of the NIR TTS system shall not exceed 10 minutes.

19. The time required to initialize the NIR TTS system shall not exceed 10 minutes. This initialization refers to the associated computer systems, software and motion control devices. The NIR TTS camera is assumed to be at operating temperature.

20. The NIR TTS system shall not increase the typical LGS AO acquisition time by more than 15 seconds.

21. Other than acquisition time, the NIR TTS system shall not reduce the observing efficiency of the current LGS AO system. Observing efficiency includes the time to perform such tasks as nodding, dithering and offsetting.

22. The NIR TTS system shall support differential atmospheric refraction corrections between the TTS and the science instrument for a ≤ 20 minute science exposure for zenith angles ≤ 60°, with performance consistent with system requirement #4.

23. The NIR TTS system shall support normal science observing modes such as dithering, nodding and offsetting.
    Definitions:
    1) Micro-dithering is performed to finely position a science object on the science detector.
    2) Dithering is performed to move a science object around the science detector.

3) Offsetting is performed to mosaic an image, to obtain a measurement of the sky background, or to perform a blind offset from a reference star to the science target when the science target is not visible on the detector. Nodding is considered to be the same as offsetting.
The amplitudes and accuracy of these moves are defined in SR-24 and SR-25.

24. The NIR TTS system shall be able to position an object on the science instrument to an accuracy of ≤ 120 mas (3-sigma) for moves ≤ 60 arcsec and ≤ 70 mas for moves ≤ 5 arcsec (i.e., a dither), assuming the tip-tilt star stays within the NIR TTS field of view.
25. The NIR TTS system shall be able to reposition an object on the science instrument to a relative accuracy of ≤ 5 mas for moves ≤ 20 mas (i.e., a micro-dither), assuming the NIR TTS system tip-tilt loop was already closed.
26. The stability of the NIR TTS with respect to the AO bench shall be ≤ 5 mas over a 1 hour exposure, assuming a temperature change of ≤ 1° C.
27. The NIR TTS system shall be able to reposition an object on the science instrument to ≤ 10 mas precision after an intermediate move of ≤ 10 arcsec, in support of dithering.
28. The NIR TTS system is not expected to support non-sidereal tracking; this mode will continue to be supported by STRAP. As a goal, the NIR TTS system shall be able to maintain the position of a non-sidereal object on the science instrument to ≤ 5 mas for a non-sidereal object with a deviation rate of 50 arcseconds per hour or less, assuming the tip-tilt star stays within the NIR TTS field of view.
29. As a goal the NIR TTS shall support fixed pupil mode. In this mode the NIR TTS shall be able to maintain the position of science object on the science instrument to ≤ 5 mas for an off-axis tip-tilt star that remains on the NIR TTS throughout the observation. This mode need only be supported during meridian transiting within ≥ 5° (TBC) from the zenith.
30. As a goal the NIR TTS should provide some measure of performance. Desired quantities include a Strehl measurement and a measure of the seeing disk profile (a two component Gaussian fit has been suggested) plus a relative photometry measurement for each tip-tilt star.
31. The NIR TTS system shall meet all of its performance requirements in the operating environment conditions given in Table 2.

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Temperature					
Range	-10	0	20	°C	1
Rate of change	-0.8	-	0.8	°C/h	
Humidity	0	-	90	%	2
Gravity orientation	-	-1	-	g	3
Vibration	-	-	$1x10^{-5}$	g^2/Hz	4
Acceleration	-	-	1	g	5

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20 Hz to 1000 Hz, 6db/oct drop- off to 2000 Hz.
5. All axes, due to telescope drive system fault conditions.

Table 2: Operating environment

32. Provide the ability to operate the NIR TTS with the high order NGS WFS in "dual NGS" mode to support development & testing.

4.2 Optical Requirements

33. The unvignetted field of view of the NIR TTS shall be at least a 100" diameter circle with a goal of a 120" diameter circle.
34. The operational wavelengths of the NIR TTS shall be the short wavelength end of K-band (e.g. Ks or K') and H-band. Only one of these bands will be used at any given time.
35. When the NIR TTS system is used the transmission in the science wavelength shall not be reduced by more than 5%. The goal is 3%.
36. When the NIR TTS system is used the emissivity in the science wavelength shall not be increased by more than 5% averaged over the science band. The goal is 3%.

4.3 Mechanical Requirements

37. The NIR TTS system shall not introduce vibrations into the LGS AO system that would impact science performance. This requirement is already covered by requirement 4 but is included here to draw specific attention to the importance of minimizing vibrations.
38. The NIR TTS system shall not mechanically interfere with the components already on the AO bench, unless these components can be and are appropriately modified to support the integration of the NIR TTS system.
39. The NIR TTS system mounted on the AO bench shall not exceed a total mass of 70 kg (TBC).
40. The associated NIR TTS system equipment not on the AO bench shall not exceed a TBD envelope.

4.4 Electronic/Electrical Requirements

41. The NIR TTS system shall use less than or equal to TBD of electrical power.
42. The NIR TTS system on the AO bench shall not exceed a one-hour average heat dissipation of 5 Watts into the AO bench environment.
43. The associated NIR TTS system equipment not on the AO bench shall not exceed a one-hour average heat dissipation of 10 Watts into the AO clean room.
44. If practical the NIR TTS system electronics shall be located in a rack in the AO electronics room and cables must be of appropriate length to reach these locations. If cable lengths are required to be shorter, then the cables shall be at least long enough to allow placing this equipment outside of the enclosure directly around the AO bench.

4.5 Safety Requirements

45. The NIR TTS system shall be able to withstand the acceleration profile (to be provided) without damage or severe misalignment. Restraints should be provided to prevent hardware from damaging itself or other hardware during an earthquake.

4.6 Software Requirements

46. The NIR TTS system shall provide the needed operational tools to support its daytime calibration.
47. The NIR TTS system shall provide the needed tools to support science observation planning.
48. The NIR TTS system shall provide the needed operational tools to support nighttime science operations.

4.7 Interface / Logging Requirements

49. The NIR TTS system must support an interface to the Observatory standard KTL keywords. For example, command and status communications between the NIR TTS camera system and the optics bench, supervisory controller and operations software shall be via keywords.

50. All telemetry from the NIR TTS should be provided to the existing telemetry server.

51. The NIR TTS system shall be capable of saving images in FITS format.

4.8 Spares Requirements

52. The spare NGWFC electronics hardware setup currently available in WMKO HQ shall be updated to match the final hardware configuration that will be designed for the NIR TTS project.

4.9 Reliability

53. The NIR TTS system shall meet all of its performance requirements without repair after shipment to Keck headquarters and to the telescope.

54. The NIR TTS system shall have a lifetime of ≥ 10 years.

55. The NIR TTS system shall be capable of operating on ≥ 200 nights per year.

56. The NIR TTS system shall lose no more than 5% of its total observing time to faults.

57. The NIR TTS system shall have a median time between faults that result in ≥ 10 minutes of lost observing time, of ≥ 10 nights of operation.

58. The time to restart the NIR TTS system shall not exceed 10 minutes.

59. The NIR TTS system shall meet all of its performance requirements without repair or realignment after being subjected to any number of cycles of any of the non-operating environmental conditions shown in Table 3.

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Temperature					
Range	-10	0	30	°C	1
Rate of change	-0.8	-	0.8	°C/h	
Humidity	0	-	90	%	2
Gravity orientation	-	-1	-	g	3
Vibration	-	-	8.0×10^{-4}	g^2/Hz	4
Shock	-	-	15	g	5
Acceleration					
Due to handling	-	-	-	g	6
Due to seismic activity	-	-	2	g	7

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20 Hz to 1000 Hz, 6db/oct drop- off to 2000 Hz.
5. 0.015 second half-sine, all axes.
6. 2 g vertical, 1 g fore/aft, 0.5 g lateral.
7. 0.5 Hz to 100Hz, all axes.

Table 3: Non-operating environment

60. The NIR TTS system shall be able to withstand a total and sudden loss of electrical power or a transient power event, without suffering damage.

61. The NIR TTS system shall be able to operate without telemetry logging in the event that the Telemetry Recorder System (TRS) is non-operational.

4.10 Service and Maintenance

62. AO system unavailability or downtime to install and integrate the NIR TTS system shall not exceed 2 weeks.

63. Routine maintenance on the NIR TTS shall not require more than 1 technician for 4 hours every 4 months.

4.11 Documentation Requirements

64. The NIR TTS system shall be provided with the documentation required to understand and document its as-built design, and to maintain and operate it.

65. The NIR TTS system shall be provided with the documentation required to support science operations planning. This should include at least 3 months of performance characterization data after the system has begun being used for shared-risk science.

66. Goal: The NIR TTS system shall be provided with a performance estimation tool for both pre-observing planning and observing. This would be even more useful with a PSF simulator attached to it.

67. The NIR TTS system shall successfully complete a handover review, with TBD success criteria, before being transferred to the responsibility of the AO operations group.

4.12 Configuration Management Requirements

68. All code changes and documentation updates shall be managed according to existing WMKO configuration management practices.

69. All software releases on the operational system shall be revertible to an on-sky demonstrated software release within 15 (TBC) minutes.

70. The NIR TTS system shall receive approval from the AO configuration control board prior to implementation into the Keck I LGS AO system.