KAON #754

Next Generation Adaptive Optics System

Laser Traffic Control System Modifications

Preliminary Design

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1 INTRODUCTION

As part of the Next Generation Adaptive Optics System (NGAO), a Laser Traffic Control System (LTCS) is needed to ensure the lasers in the system do not impact observations of other observatories. The impetus for this requirement comes from the Mauna Kea Observatories Working Group composed of representatives from observatories on the mountain. The initial policy statement for Mauna Kea required that a laser equipped telescope must yield (shutter) for a non laser equipped telescope when the non-lasing telescope indicated sensitivity to laser emissions and a crossing geometry occurs. Following the initial policy statement, a revised statement for Mauna Kea was issued that allows for lasing telescopes that are first-on-target to continue lasing, even if the laser impacts a field of view of a non-lasing telescope. In either case, each participating telescope is responsible for providing a position, field of view (FOV), and a laser sensitivity indicator. A safety system installed at the lasing facility performs necessary calculations using the provided information to predict collisions and shutter as needed to prevent contamination of science data with unwanted emission. The safety system responsible for these calculations is the Laser Traffic Control System.

The LTCS is in place for both Keck I and Keck 2 laser operations. This document provides a preliminary design of what modifications must be made and their impact due to NGAO requirements.

2 REFERENCES

2.1 Referenced Documents

Documents referenced are listed in Table 1. Copies of these documents may be obtained from the source listed in the table.

Ref. #	Document #	Revision or Effective Date	Source	Title
1	LTCS Web Pages	-	WMKO Intranet	http://www/TWiki/bin/view/Main/LaserTrafficControlSystem
2		1.3	WMKO	Mauna Kea LTCS URL Interface Specification
3		1.0	WMKO	Laser Traffic Control System: Software Design Book

Table 1: Reference Document.

2.2 Acronyms and Abbreviations

Table 2 defines the acronyms and abbreviations used in this document.

Acronym/Abbreviation	Definition
FOV	Field of View
GUI	Graphical User Interface
HTML	HyperText Markup Language
ICD	Interface Control Document
KAON	Keck Adaptive Optics Note
LGS	Laser Guide Star
LSS	Laser Safety System
LTCS	Laser Traffic Control System
MKLGSTWG	Mauna Kea Laser Guide Star Technical Working Group
NGAO	Next Generation Adaptive Optics System
NGS	Natural Guide Star
PHP	HyperText Pre-processor language
URL	Uniform Resource Locator
WMKO	W.M.K. Observatory

Table 2: Acronyms and Abbreviations.

3 LASER TRAFFIC CONTROL SYSTEM MODIFICATIONS

An existing Laser Traffic Control System design is in operation on the Keck II telescope. The existing design models a cylindrical laser beam extending from the Keck II off-axis projection launch telescope, through the Rayleigh scatter, and through the mesospheric sodium column. Modifications will be needed to modify this geometry for the dynamically changing NGAO constellation FOV, centrally projected from behind the f/15 secondary module.

3.1 Laser Constellation Format

From KAON 562, NGAO outputs a total of seven laser beams. This contrasts with the single beam that currently exists on Keck 1 and Keck 2. The NGAO constellation of the beams for NGAO is shown in Figure 1. The total expected field of view is +/- 60".

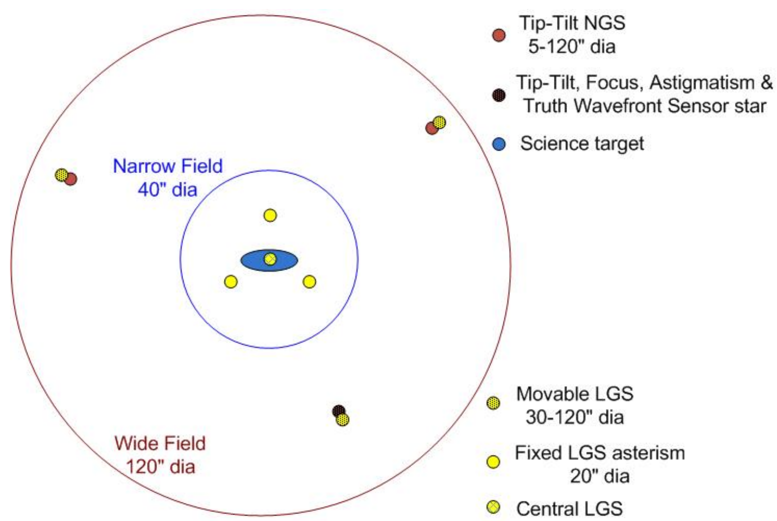

Figure 1 LGS "3+1" asterism for tomography of the science field, plus three patrolling lasers for image sharpening of the tip-tilt stars

3.2 Design Choices

The current LTCS cylindrical beam model should not be used for NGAO. In its current implementation, LTCS uses a cylindrical beam to model the laser. To use the existing design would require a laser beam size specification of nearly 50 meters (86 km sodium height above Keck and a 120 arcsecond max FOV footprint on sky). This would pose an obvious problem for low elevation Rayleigh collision calculations. Based on the NGAO constellation geometry, LTCS will need to be modified. The seven lasers can be modelled in multiple ways. One possible method would be to represent the individual beams as 7 distinct cylinders. Another method might be to model the entire constellation as a cone (covering the full extent of the emission field). A third method might be to model the constellation as a mixed / hybrid configuration (containing a cone for the central fixed asterism, and separate cylinders for the configurable Tip-Tilt lasers). The hybrid approach will not be discussed further as it is only a combination of the two other possible methods. The issues associated with modelling the beams separately and as a cone are further described in the paragraphs below.

3.2.1 Seven Individual Beams

In this configuration, seven cylindrical beams would be modelled by LTCS. Each beam would require its own pointing information. This configuration requires the most information, but has the advantage of allowing for the best geometric model of the beams, theoretically minimizing the collision potential with other telescopes. A telescope with a sufficiently small laser impacted guider/instrument FOV might be able to split the constellation (i.e. split the gaps in the tip/tilt laser configuration), avoiding a collision. However, the maximum size of the outer beam gaps is small (approximately 45 arcseconds). The maximum gap can be calculated from knowing the fixed central constellation footprint, the beam size of an individual laser, and the maximum tip/tilt laser displacement from the center. Each individual beam is assumed to be ~0.5 meters wide. The maximum beam separation at 90 kilometers sodium height (~86km above Keck II) is approximately 25 meters (radius). Assuming a central region footprint of approximately 4 meters (radius), the angular gap between a maximized outer constellation and the inner central footprint would be approximately 49 arcseconds. While this is theoretically possible to split with the right guider/instrument configuration, in practice it is not likely.

While the advantage of modelling the constellation as 7 different beams allows for minimizing the potential for collisions, the disadvantages of this approach considerably outweigh the minimized collision advantage. The disadvantages of a seven different beam LTCS design implementation are as follows:

a. Each beam would require its own pointing information to be passed through the LTCS URL interface, into the collector, and through the GA engine into the calculator. This would make the URL interface and supporting code significantly more complicated due to the number of new parameters crossing each interface.

b. The user GUIs could be considerably more difficult to comprehend. Where a single beam approach might show a single collision between a laser and telescope, the GUI interface for a 7 laser constellation might show many different collisions (all with different start/end times). There are approaches that might help to minimize GUI confusion (bundle all reports together for presentation), but this approach might have its own technical drawbacks (collision prediction timing might not appear consistent for gaps).

c. A considerable amount of additional code complexity would be required to implement this solution. Either the upper level Java code would need an additional wrapper to call collision calculations for each independent laser, or the underlying C code would need to be modified to pass all lasers and make 7 calculations. From a complexity perspective, the most simple solution would be to modify the upper level Java code and call the calculator N times with each laser's pointing information.

d. Calculation performance would be a concern. LTCS is currently able to process a 3 hour forward projection of beam collision geometry in ~200 milliseconds (includes worst case collision scenario). Calculation performance would decrease linearly for the additional lasers in a multi-laser configuration. For 7 lasers, the calc time would be approximately 1.5 seconds. A faster processor, or a parallel computing approach might reduce this time. Both queries and core safety system performance would be impacted.

3.2.2 Fixed Cone of Laser Beams

As opposed to a model in which 7 independent beams are modelled, or a model in which the entire constellation is treated as a single, oversized cylinder (sized for maximum footprint at the sodium layer height), the entire constellation might be simply and effectively modelled as a cone radiating from the central projector, with a maximum extent given by the tip/tilt laser with the furthest extent from the central constellation. The current cylindrical model would be replaced by a cone model that specifies the FOV angular extent using the information from the supporting tip/tilt lasers.

The advantages of this design are as follows:

a. The code would gracefully handle a dynamically changing constellation FOV, consistent with the anticipated NGAO operations model. The FOV would need to be calculated and presented to the URL, but this would be trivial.

b. The existing LTCS code modifications would be limited; only the central laser pointing information and constellation FOV are required to be passed via the URL interface into the geometric calculator. The calculator itself will require a modification to handle the cone FOV, but this change isn't considered major.

c. The user GUIs remain simple; a collision of the cone will show as a single entity with consistent start/end times.

The disadvantage of this approach is that the larger cone will result in a slightly higher closure rate (assumes a very small FOV instrument or non-impacted guider capable of splitting the gaps). This may not be a reasonable assumption, thus eliminating any potential for reduced collisions. Based upon this, the recommended design solution is to move forward with a cone based solution.

3.3 Modifications to software

LTCS is composed of a C code calculator "core" that calculates beam geometry for a single laser and telescope pair. This C code is called by a Java wrapper that handles the nuances of managing a site configuration composed of N telescopes and M lasers, making calls as appropriate for laser status and telescope laser impacted state. A separate Java process addresses database storage of status information (used by the GUIs) and for logging. Three Java processes support calculator inputs and outputs. These include the collector (web collection of remote and local telescope URL data; provided to the calculator), the GA (geometric analysis) engine (used to manage the site configuration), and Status Manager (database and reporting abstraction). User GUIs are written in PHP and HTML. A mysql database holds state information for telescopes, lasers, and collision data.

An important implementation note to consider is the fact that the current LTCS does not currently support laser pointing information. Rather, the laser pointing is inferred from telescope pointing. This is a design flaw that may need to be addressed before or during the NGAO design. Without pointing information for the laser, the telescope pointing is assumed (on-axis laser pointing assumption). If the cone is sized relative to the optical axis, this will not be an issue. If the central constellation will not be on axis (i.e. offset using field steering), then the laser cone will need to be either sized to accommodate the largest off-axis position of the central constellation, or laser pointing will be needed in the interface. Given that both Keck I and Keck II have the ability to steer the laser off-axis, this should be addressed at some point with a modification to allow laser pointing information to be explicitly set. In a worst case scenario where the laser is offset from the telescope, but on-axis telescope pointing is assumed, LTCS would incorrectly calculate the pointing and science data may be exposed to laser emission unnecessarily.

4 INTERFACES

4.1 Software

The LTCS shall interface to the NGAO Safety System according to the existing interface with the KI and Keck II Laser Safety Systems (LSS). This interface is via a RS232 interface on the Keck I system. This interface may be upgraded to an Ethernet connection. The existing GUIs are sufficient to support NGAO; no modifications will be required. A keyword permissive already exists that is set by LTCS and read by the safety system. When necessary, LTCS sets the permissive to GRANT (no collision) or DENY (causing a shutter). LTCS maintains the collision projected time (entry/exit), and has the ability to debounce shutter events for collision cycling (by configuration specification). Only a single instance of LTCS is required to be run for Keck I and Keck II; keyword access to either the Keck I or Keck II laser shutter has already been implemented.

4.2 Hardware

Depending on the selected implementation model for LTCS, a larger processor may be required to enhance calculation and query performance. The suggested solution of a cone model for the lasers does not require a larger processor; independent modelling of the 7 separate laser beams may require a faster processor.

5 COMPLIANCE MATRIX

The design meets the requirements as specified by the Mauna Kea Laser Guide Star Technical Working Group (MKLGSTWG) and LTCS Software Design Book. NGAO compliance is provided in the LGSF Compliance Matrix.

6 PERFORMANCE AND IMPACT TO OPERATIONS

Calculation performance impact for a cone based constellation solution (as opposed to a cylindrical model) will be minimally greater. A 120 arcsecond FOV is significantly larger than the current single 1 arcsecond laser footprint. However, the majority of collisions occur at lower elevation angles (Rayleigh collisions). As such, the expected collision geometries are smaller than those affecting the sodium spot. The expected beam collisions will be greater for Keck I and Subaru due to proximity.

7 RECOMMENDATIONS

As has been previously discussed in the design discussion, it is recommended that LTCS be modified to have the core algorithm support a cone based laser beam modelling approach. In addition, if the laser constellation is to be capable of significant off-axis pointing, it may be advisable to address laser pointing as an explicit parameter of the LTCS URL specification. Since LTCS is already in place for Keck I and Keck 2, it is recommended the work completed for NGAO LTCS can fall under the Engineering Change Control Process.

8 MANAGEMENT

8.1 Budget

Budget estimates are provided in the overall NGAO cost summary.

8.2 Schedule

In terms of schedule, the effort is not significant as compared to the overall plan and will be added to the overall NGAO schedule.

8.3 Risk Assessment

The risk to implement a cone solution modification to the existing design is considered low or very low, with a consequence of occurrence projection of 1 (minimal or no impact). The risk for implementing a 7 beam solution is considered moderate due to the number of changes required through out the existing code baseline, and unknowns in how to minimize confusion in the user GUIs.

9 PLANS FOR DDR PHASE

In the Detailed Design Phase, the URL specification will be modified to support both laser pointing parameters, and the constellation FOV. The existing LTCS design document will be updated to reflect the new design approach. Note that the LTCS design document has become stale and partially incorrect for the existing design. Some additional work to update the document for NGAO use is anticipated.

LTCS is completely data driven, eliminating the requirement to have dedicated telescope and laser time for testing purposes. A stand-alone version of the core calculator is available for testing against typical/nominal use cases; this calculator can also be used for some pathological testing. LTCS regression testing will be required to reverify all existing functions, but fortunately, the proposed implementation approach is isolated to a very small section of the core calculator and its supporting input interfaces. This reduces the overall impact and need for detailed regression testing. Pathological and nominal / typical use cases are well known given past LTCS code modifications. Testing a beam cone model can be done using simple analysis and simulation using the existing data driven URL and flat file methods.

Detailed Design Phase Deliverables

- Implementation plans.
- Further risk reduction.
- Version Control
- Keyword description
- Final ICD if any.
- More firm budget and schedule.
- Documentation on procedures and operations if any.