Second Generation Laser Traffic Control; Algorithm Changes Supporting Mauna Kea, La Palma, and Future Multi-Telescope Laser sites

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ABSTRACT

A Laser Traffic Control System (LTCS) for laser beam avoidance has been in use at the W. M. Keck observatory on Mauna Kea since 2002. Subsequent LTCS installations have occurred at Gemini North (2003), and at the William Herschel Telescope on La Palma, Canary Islands (2005). Gemini North laser tests in 2005 necessitated algorithm changes to provide support for multiple laser configurations. Operational differences for how laser-telescope priority resolutions occur on La Palma vs. Mauna Kea necessitated algorithm changes to address more generic specification of priority rules, collision event queries, and better display feedback. A joint collaboration between the W. M. Keck observatory and the Isaac Newton Group, to install the LTCS at La Palma and enhance its priority processing algorithm and display functions, occurred in 2005. The changes made should be sufficient to support LTCS software implementations at many different sites, current and future, where multiple laser/telescope configurations are planned. This paper will describe the algorithm changes, review outstanding issues, and describe planned development activities supporting a broader use potential to include sites with ELTs.

Keywords: laser guide star, adaptive optics, laser traffic control software, Mauna Kea, Isaac Newton Group

1. INTRODUCTION

The concept of a laser safety system to avoid LGS and/or Rayleigh "collisions" between laser equipped telescopes, and the fields of view of collocated non-laser equipped telescopes, was originally considered by Wizinowich et. al[1]. A "first generation" LTCS system was subsequently developed as a collaborative effort of multiple facilities on Mauna Kea[2,3]. The initial LTCS was capable of supporting multiple telescopes and a single laser equipped telescope. Its shutter priority rule was simple; telescopes were always given priority over a laser equipped telescope when in collision. Initial LTCS development occurred between July 2001 and December 2001. Supplemental development has occurred since then to improve core functionality. The LTCS is now an integral safety component for routine LGS AO science operations on Mauna Kea. The first generation LTCS core consisted of ~12.5K lines of Java, C, and PHP, running under Solaris and/or Linux operating systems[4]. The LTCS uses 3rd party software libraries and products including Slalib, Log4J, MySql (or Postgres), and Apache web server.

The idea to reuse LTCS for the first operational laser beacon on La Palma at the William Herschel Telescope (WHT), for the 515nm Rayleigh Ground-layer Laser AO System (GLAS)[5], started with preliminary discussions during the SPIE Astronomical Telescopes and Instrumentation (ATI) conference in Waikoloa Hawaii, 2002. Additional discussions were held during the SPIE ATI conference in Glasgow Scotland, 2004. Following these discussions, an agreement was reached between the Isaac Newton Group (ING) and the W. M. Keck Observatory, to fund a collaborative LTCS effort. The primary author traveled to La Palma, Spain in March 2005 to support configuration of La Palma as a new LTCS site. During the effort, it became obvious that a different concept for priority rules was desired for use on La Palma. The team proceeded to configure LTCS for the La Palma Site, Observatorio de Roque de los Muchachos, but also spent time designing a configurable priority scheme suitable for reuse. The La Palma team continued design and development

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activities, creating several design documents and code enhancements. These included support for priority rules, queries, location uncertainty, and time-on-target logic[6,7,8,9]. During the period from November 2005 to March 2006, the Keck configuration was retrofitted to incorporate the La Palma enhancements. Further development occurred at Keck to refine these enhancements, and add operations features (primarily support for multiple laser equipped telescopes, and slew detection/filtering). The new software comprises the second generation LTCS. The second generation LTCS core is ~15.5K lines of code. It is capable of supporting most any configuration of telescopes and single beam laser equipped telescopes operating via URL based telescope pointing data notifications.

For the remainder of this paper, we will use the term "facility" to denote telescopes and laser-equipped telescopes. The term "site" will be used to denote a mountain upon which telescope and laser facilities reside.

1.1 LTCS Architecture & Design Overview

LTCS core functions are implemented within three executable processes communicating via TCP/IP. A central database, multiple operator GUIs, and site specific scripts are used to access core system data. The executable processes manage connections, gather pointing data from each observatory, report state transitions (Collector), calculate beam geometries (Geometric Analysis (GA)), and support status reporting and database updates for state transitions, collision predictions, and shutter events (Status Manager). The database information is used for both GUI updates and for any desired site specific LTCS extensions. The LTCS Software architecture is shown in Figure 1.

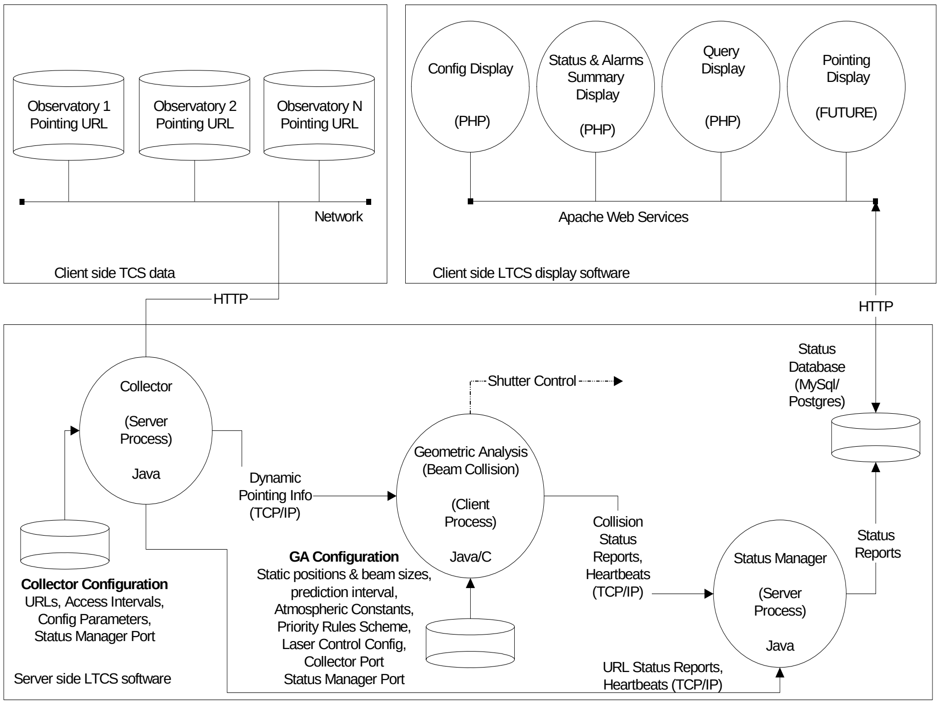


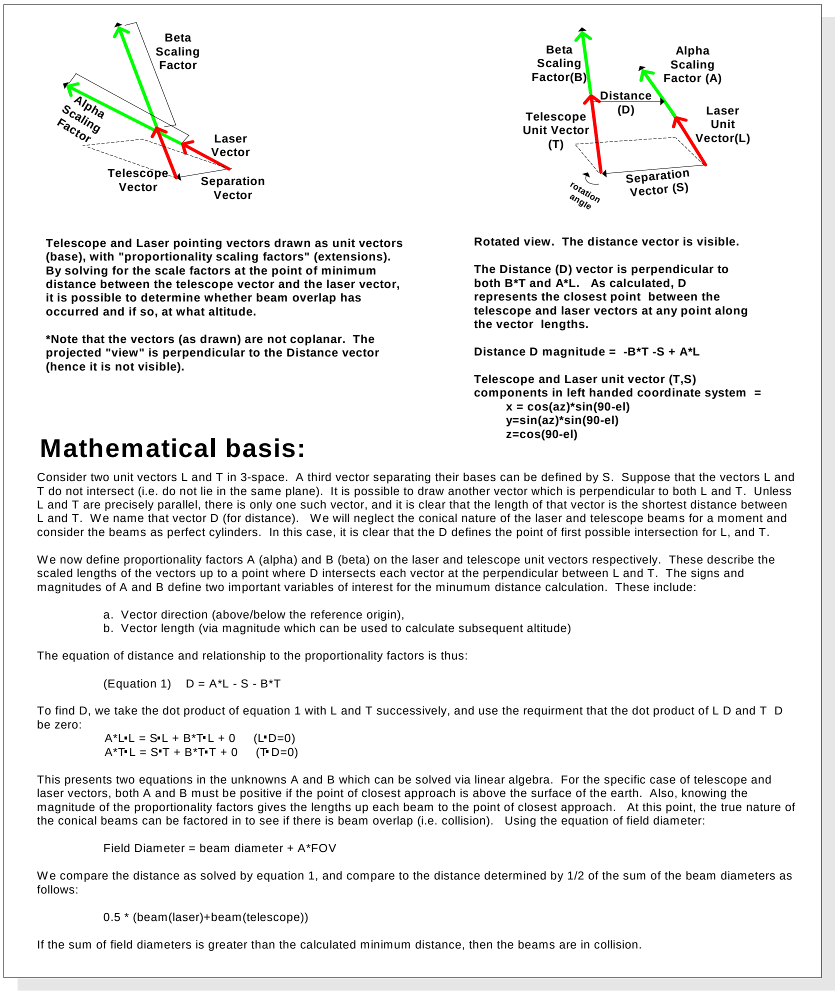
Figure 1 - LTCS Software Architecture

1.1.1 Collector

A "smart" collector design has been implemented. The collector is a multi-threaded, Java client that collects all telescope pointing data from remote URL servers. It acts as the managing server for pointing data into the Geometric Analysis (GA) engine. The collector manages most facility state transitions. It is able to detect current, stale, and redundant pointing data, and act as necessary, even to remove and/or restore facilities from LTCS calculations. It is "aware" of the difference between real and simulated calculation modes. It manages routing of query and simulated preview requests to the Geometric Analysis Engine (GA). The collector also has ability to detect and filter facilities that slew while reporting laser sensitivity. A configuration file sets all relevant parameters for each facility. A URL specification has been written that describes in detail the requirements for transmitting facility pointing information[3].

1.1.2 Geometric Analysis Engine

The Geometric Analysis Engine (GA) is a multi-threaded Java client for system pointing data. It calculates and predicts collision geometries. It typically is used to control a single laser's shutter, but calculates and reports collisions and collision predictions for all laser equipped telescopes in a configuration. Collisions are calculated for all laser equipped telescopes that report a state of "ON" or "ON-SKY", and for all telescopes that report sensitivity to laser emission. The GA manages calculations, predictions, collision data storage, and cleanup. It has the capability to queue and swap shutter events as necessary to ensure all collision geometries are handled properly. The software algorithm uses static location information, dynamic URL pointing updates (RA, DEC, Equinox), Rayleigh height, and sodium height (for LGS facilities) to help determine collision geometries. At the core of the algorithm, a distance between beams calculation is performed using position data, vector analysis, and vector overlays of the telescope FOV and the laser beam. Figure 2 describes the vector analysis. Figure 3 shows an example of simple, non-colliding beam geometry. Figure 4 shows details of the beam geometry overlay concept. Additional LTCS algorithm information for when and how calculations are performed is provided in Summers et.al[2]. Note that LTCS supports Rayleigh beam and sodium LGS configurations.



Telescope and Laser pointing vectors drawn as unit vectors (base), with "proportionality scaling factors" (extensions). By solving for the scale factors at the point of minimum distance between the telescope vector and the laser vector, it is possible to determine whether beam overlap has occurred and if so, at what altitude.

***Note that the vectors (as drawn) are not coplanar. The projected "view" is perpendicular to the Distance vector (hence it is not visible).**

Rotated view. The distance vector is visible.

The Distance (D) vector is perpendicular to both B*T and A*L. As calculated, D represents the closest point between the telescope and laser vectors at any point along the vector lengths.

Distance D magnitude = $-B*T - S + A*L$

Telescope and Laser unit vector (T,S) components in left handed coordinate system =

$x = \cos(az)*\sin(90-el)$
$y=\sin(az)*\sin(90-el)$
$z=\cos(90-el)$

Mathematical basis:

Consider two unit vectors L and T in 3-space. A third vector separating their bases can be defined by S. Suppose that the vectors L and T do not intersect (i.e. do not lie in the same plane). It is possible to draw another vector which is perpendicular to both L and T. Unless L and T are precisely parallel, there is only one such vector, and it is clear that the length of that vector is the shortest distance between L and T. We name that vector D (for distance). We will neglect the conical nature of the laser and telescope beams for a moment and consider the beams as perfect cylinders. In this case, it is clear that the D defines the point of first possible intersection for L, and T.

We now define proportionality factors A (alpha) and B (beta) on the laser and telescope unit vectors respectively. These describe the scaled lengths of the vectors up to a point where D intersects each vector at the perpendicular between L and T. The signs and magnitudes of A and B define two important variables of interest for the minumum distance calculation. These include:

a. Vector direction (above/below the reference origin),
b. Vector length (via magnitude which can be used to calculate subsequent altitude)

The equation of distance and relationship to the proportionality factors is thus:

(Equation 1) $D = A*L - S - B*T$

To find D, we take the dot product of equation 1 with L and T successively, and use the requirment that the dot product of L D and T D be zero:

$A*L\cdot L = S\cdot L + B*T\cdot L + 0 \quad (L\cdot D=0)$
$A*T\cdot L = S\cdot T + B*T\cdot T + 0 \quad (T\cdot D=0)$

This presents two equations in the unknowns A and B which can be solved via linear algebra. For the specific case of telescope and laser vectors, both A and B must be positive if the point of closest approach is above the surface of the earth. Also, knowing the magnitude of the proportionality factors gives the lengths up each beam to the point of closest approach. At this point, the true nature of the conical beams can be factored in to see if there is beam overlap (i.e. collision). Using the equation of field diameter:

Field Diameter = beam diameter + A*FOV

We compare the distance as solved by equation 1, and compare to the distance determined by 1/2 of the sum of the beam diameters as follows:

$0.5 * (beam(laser)+beam(telescope))$

If the sum of field diameters is greater than the calculated minimum distance, then the beams are in collision.

Figure 2 – Distance between beams algorithm using vector analysis

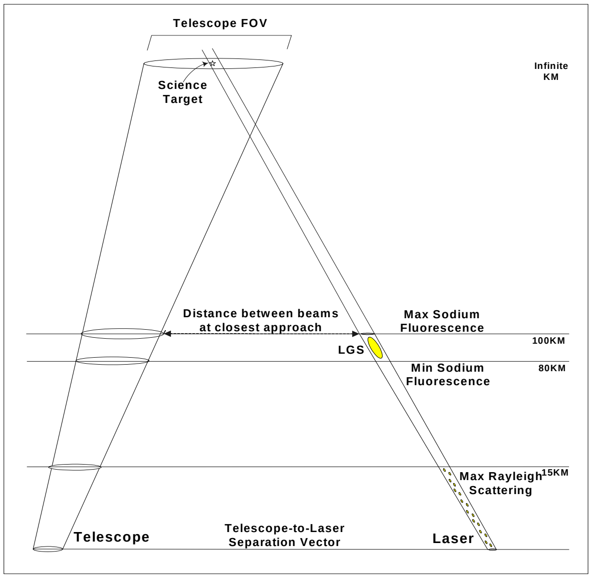
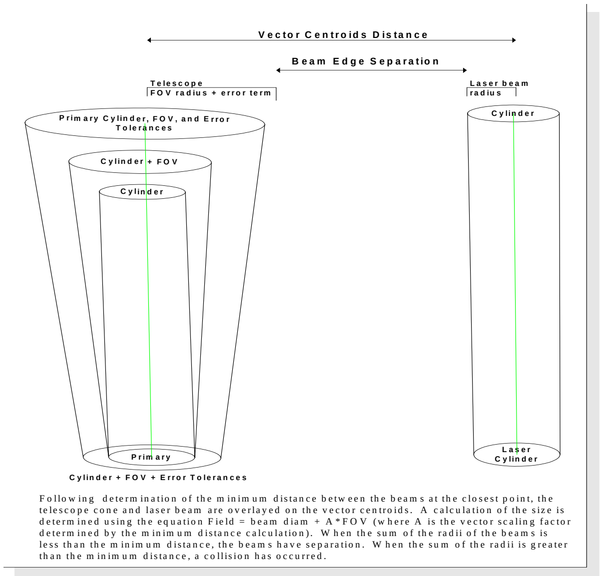


Figure 3 – Example telescope and laser geometry

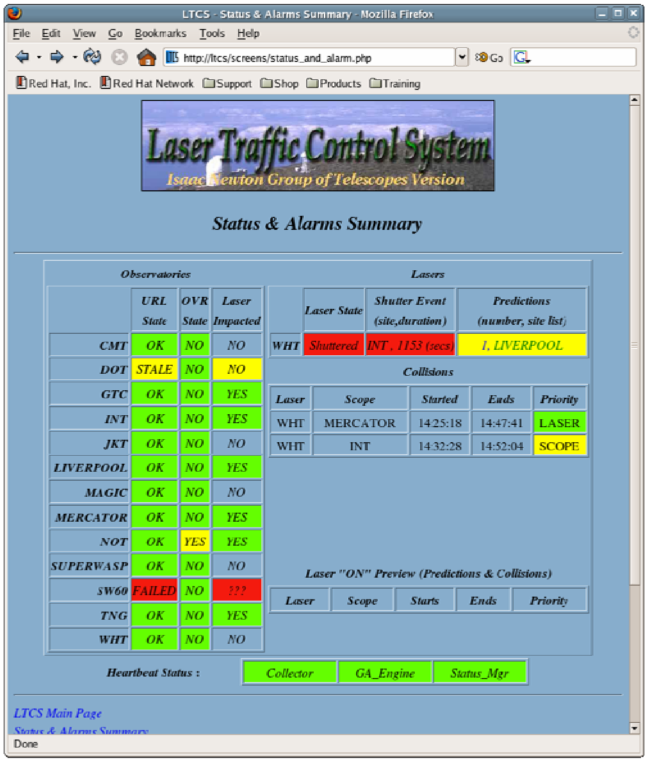


Following determination of the minimum distance between the beams at the closest point, the telescope cone and laser beam are overlayed on the vector centroids. A calculation of the size is determined using the equation Field = beam diam + A*FOV (where A is the vector scaling factor determined by the minimum distance calculation). When the sum of the radii of the beams is less than the minimum distance, the beams have separation. When the sum of the radii is greater than the minimum distance, a collision has occurred.

Figure 4 – Overlay of FOV and laser beam

1.1.3 Status/Displays

Operators view LTCS information via 3 major web based GUIs. These GUIs include the status and alarm summary, a configuration/override tool, and a query tool. The web pages access LTCS data indirectly through database dips using PHP. The Status & Alarm Summary GUI is the primary operator interface displaying all critical system information. This GUI is shown in Figure 5.



Status & Alarms Summary

Observatories

	URL State	OVR State	Laser Impacted
CMT	OK	NO	NO
DOT	STALE	NO	NO
GTC	OK	NO	YES
INT	OK	NO	YES
JKT	OK	NO	NO
LIVERPOOL	OK	NO	YES
MAGIC	OK	NO	NO
MERCATOR	OK	NO	YES
NOT	OK	YES	YES
SUPERWASP	OK	NO	NO
SW60	FAILED	NO	???
TNG	OK	NO	YES
WHT	OK	NO	NO

Lasers

	Laser State	Shutter Event (site,duration)	Predictions (number, site list)
WHT	Shuttered	INT , 1153 (secs)	1, LIVERPOOL

Collisions

Laser	Scope	Started	Ends	Priority
WHT	MERCATOR	14:25:18	14:47:41	LASER
WHT	INT	14:32:28	14:52:04	SCOPE

Laser "ON" Preview (Predictions & Collisions)

Laser	Scope	Starts	Ends	Priority

Heartbeat Status : Collector GA_Engine Status_Mgr

LTCS Main Page
Status & Alarms Summary

Done

Figure 5 – Status & Alarm Summary GUI

The Status & Alarm Summary GUI shows status for facility URLs, lasers, and real / simulated predictions and collisions. Also shown is LTCS system health status.

URL status is shown in green, yellow, and red. Override states are designated yellow for clarity. Background color (blue/gray) is used for facilities that report insensitivity to laser emission (they are not subjects of calculation). Note however that regardless of laser insensitivity, a laser equipped telescope is required to calculate other facility collision geometries when its state is either "ON" or "ON-SKY".

Laser status includes the current state and any shutter events, collisions and/or predictions. Predictions support "mouse over" and pop-ups for more detail. Shutter events and collisions indicate the involved facility, duration, and which facility has been given priority.

For non-propagating lasers in an "ON" state, simulation occurs (at the current reported position). Any predicted collision is shown in a "preview" area.

Finally, system health is indicated as reported via heartbeats. The Status & Alarm summary page contains valid information only when system health indicators are green. The general convention for this GUI is that green status is normal. A yellow status indicates operator awareness is needed. A red status indicates failure, or that action is needed or has been taken by the system.

2. SECOND GENERATION LTCS FEATURES

The second generation LTCS incorporates several new features supporting globalization and operations enhancements. These include:

Globalization Enhancements	**Operational Enhancements**
Configurable Priority Rules	Multiple Simultaneous Laser Operations
Query Tools	Preview Mode
Static Location (Survey) Error	Telescope Slew Detection/Filtering
Time-on-Target determination	URL Overrides

The remaining sections of the paper introduce these new features in more detail. Following this, a discussion of current and future issues is provided. Issues are subdivided into categories addressing development, site configuration, and operations. Finally, current status and conclusions are given.

3. GLOBALIZATION ENHANCEMENTS

In the first generation LTCS, several salient features were based upon Mauna Kea conventions. The priority rule was hard coded (laser equipped telescopes yield to non-laser equipped telescopes). Mauna Kea possessed good initial site survey data for telescope locations. At La Palma, conditions differ from Mauna Kea for various reasons. Software has now been added to allow for configurable parameters related to some key differences between the sites. Priority rules have been added, and with them supporting functions related to queries and time-on-target processing. Small telescopes can now be configured with a location uncertainty error term which adds additional safety for calculations near the ground. Each of these concepts is discussed below.

3.1 Configurable Priority Rules.

Changing LTCS from using a single, static, hard coded priority rule, to a configurable priority rule based upon multiple diverse choices, allows for a wide reuse potential. Most current laser sites should find one or more operational schemes that can be used effectively. However, with configurable priority rules, it is no longer the case that laser equipped telescopes will always yield to non-laser equipped telescopes. With an increase in flexibility comes the need to be aware of which facility has priority during a collision. Both types of facilities risk laser emission in their science images if they fail to take account of how collision priority is determined. The addition of query tools (both GUI based and script enabled) allows facility operators to determine whether a collision will occur for a given observation position, and if so, the involved facility, the start / end times, and which facility has priority.

The second generation LTCS allows priority rules to be configured for one of four priority resolution schemes. The site scheme is typically established by collaboration and agreement of all participating facilities at a site. Four types of priority schemes are currently supported. These include:

1. Laser equipped telescopes yield to non-laser equipped telescopes. (note: this rule is ill-defined for use in multiple laser equipped telescope configurations).
2. Laser equipped telescopes yield to non-laser equipped telescopes, but two interacting laser equipped telescopes resolve priority based upon a “first-on-target” method.
3. Telescopes and laser equipped telescopes both resolve priority based upon a “first-on-target” method.
4. Telescopes and laser equipped telescopes resolve priority based upon each member receiving a configured priority type designator. The designator indicates the relative measure of how “active” or “passive” they should be treated during calculations. Supported priority designators include “active”, “semi-active”, and “passive”.

In the first three schemes, only the number of the priority scheme must be specified in the configuration file. For more complicated arrangements, a type 4 scheme should be defined. This requires each telescope and laser equipped telescope to have a priority designator. For laser equipped telescope interactions with non-laser equipped telescopes, there are 6 possible definition combinations resulting in 3 unique priority resolution outcomes. For interactions between two laser equipped telescopes, there are 9 possible definition combinations resulting in 6 unique priority resolution outcomes. A wide variety of special circumstances can be handled appropriately using this scheme.

Mauna Kea initially used priority scheme 1 until the capability for multiple, simultaneous, laser equipped telescopes was developed. Since then, Mauna Kea has been configured to use priority scheme 2. La Palma is currently configured for priority scheme 3. Mauna Kea has begun to investigate a transition towards a type 3 scheme. An expected recommendation for Mauna Kea to move forward to type 3, or continue with type 2, is expected in late 2006 / early 2007. There are currently no configured sites using a type 4 scheme. However, a type 4 scheme would seem appropriate for a site where a high investment ELT is to be collocated with mixed (old/new) technology. In such a location, a unique specification for each facility would allow the most efficient science return for investment. Mauna Kea may become a candidate for a type 4 scheme if a future ELT is located at the site.

3.2 Query Tools.

A query tool has long been desired by LTCS operators to assist in determining if a facility's position (current or future) will result in a beam collision. However, development on a tool was deferred until configurable priority rules were developed. A query tool went undeveloped due to the fact that facility pointing changes frequently, thus invalidating most query results. In a type 1 priority scheme (laser equipped telescopes yield to non-laser equipped telescopes), a query tool can not function as ultimately desired. Operators using such a tool in this scheme would receive a false sense of security for any query result that indicated a non-collision. Likewise, they would need to constantly re-query to test when a predicted collision would clear. On Mauna Kea, telescope pointing changes occur irregularly, but frequently (on average every couple of minutes). Thus, as would be expected for any site using a type 1 scheme, a query tool has limited utility. For similar reasons, a query tool in a type 2 scheme can only be used effectively for queries between two laser equipped telescopes.

With the advent of generic "first-on-target" determination, a query function becomes viable and vital. Operators would like to know if they can move to a new science object and expect to maintain an observation throughout an exposure. With a type 3 or type 4 scheme in effect (first on target types), query results remain valid throughout observations (assuming the telescope or laser equipped telescope is either already on target or can get on target before another gains priority through a prior move). Having a query capability becomes vital in these schemes because operationally, either type of facility may need to yield in a collision scenario. Knowing which facility has priority allows an operator to make informed decisions at the right times, keeping science operations efficient. Query tools allow an operator to input the desired pointing information, and see results of a simulated calculation. The calculation does not impact any real status fields (i.e. will not cause a shutter event). If a collision event is predicted, the information regarding involved facility, times, and which facility has priority are provided. A GUI and separate web based service have been developed such that either manual or script driven queries may be performed. Both classical and queue scheduled observing models may benefit from the available tools.

The expected use case scenario is for a site to be configured for one of the "first-on-target" schemes (type 3 or type 4). A query will be executed either by script and/or by GUI either just prior to moving the telescope to a new position or just after moving to the new position. If a query performed at a new position shows no collision predictions, then the facility is guaranteed to be able to complete its observation without having to shutter (either the laser or science camera depending on priority). As described above, queries in priority scheme types 1 and 2 must be used with skepticism.

3.3 Static Location (Survey) Uncertainty

Static facility position information is provided in the form of a reference latitude, longitude, and altitude. Each facility is configured with a North, East, and Z offset from the reference position. In the case where precise survey information is unknown (and or an uncertainty exists), a problem exists. Static position uncertainty is typically not as crucial for large telescopes as for small telescopes. On Mauna Kea, the average telescope size is large (3-4 meter class and above). On La Palma, there are several smaller telescopes. The beam avoidance algorithm in the first generation software allowed for a FOV error term to be wrapped around a telescope FOV (which provides a safety net at progressively higher altitudes). However, no corresponding safety net was provided at ground level. For small telescopes (e.g. less than 2 meters), the tolerance on static position offset from the reference location is very small, potentially resulting in inaccurate calculations. In the second generation software, a position location error has been provided as a configuration parameter. The effect is to enlarge the aperture of the telescope in the calculations, providing an extra safety factor at ground level. This approach is less awkward than intentionally over-sizing apertures in the first generation software configuration file. The uncertainty is configured in units of meters.

3.4 Time-On-Target Determination

Time on target must be calculated for three of the four priority rule schemes. A time on target is established for each facility when pointing changes beyond a configurable threshold distance value (in arc seconds). If a pointing threshold distance is exceeded during a move, a new time-on-target is set. The threshold allows for nodding / dithering without causing a new time-on-target. In this way, box patterns and mosaics don't necessarily imply lost priority during observations. Time-on-target is not based upon laser state or laser sensitivity, so these independent variables may transition as needed while still maintaining an original time-on-target.

For queries and simulated preview mode data, a time-on-target is set by reference to, and comparison against, the current (real) telescope position. Thus, if a query is performed for a simulated position (as compared against the actual reported position), the query time on target is reset (as if the telescope had actually moved). This simulation convention provides priority resolutions as would be expected if the moves and calculations were performed for real.

4. OPERATIONAL ENHANCEMENTS

The enhancements falling under this category were all developed as a means to satisfy operational considerations during use on Mauna Kea. These improvements include an ability to support multiple simultaneously operating laser equipped telescopes, provide simulated "previews" of laser collision predictions, detect (and potentially filter) telescope slew conditions, and allow for feature extension of URL overrides. Each of these features is discussed in more detail below.

4.1 Multiple Simultaneous Laser Equipped Telescope Operations.

With the maturity of LGS AO program plans at several major observatories, the need to support multiple, simultaneous, laser equipped telescopes has become a necessity. On Mauna Kea, there are operating lasers on Keck2 and Gemini. Detailed plans for use of lasers on Subaru and Keck1exist as well. In the first generation LTCS software, multiple laser equipped telescopes could be configured, but only one of these laser equipped telescopes could propagate on a given night. The software could not correctly distinguish the difference between a laser equipped telescope acting as a laser, and a laser equipped telescope acting without its laser (i.e. as a normal telescope). As such, the internal data structures for laser equipped telescopes could not be updated correctly. This defect is partly due to a design flaw in the original system URL specification (by only allowing two reported laser states ("ON" or "OFF")), and partly due to additional algorithmic processing of laser equipped telescope data structures needed to make all state transitions work as expected. In the second generation LTCS, new code to process transitions has been added, and a third state was introduced. One of the old laser reporting states has changed meaning.

Laser states are now specified as "OFF", "ON", or "ON-SKY". A laser equipped telescope that reports "OFF" is actually a telescope for the purpose of resolving priority. A laser equipped telescope that reports itself "ON" or "ON-SKY" is stating an intention to operate as a laser equipped telescope for priority resolution. A revised URL specification provides guidance for how to correctly set the laser_state field[3]. A laser equipped telescope reporting a state of "ON", is in a state of ***potential*** propagation. This would be a typical state reported during pre-propagation setup, new position moves, or for activities such as taking sky backgrounds. A laser equipped telescope in an "ON-SKY" state is considered propagating. Calculations are performed and shutter (and/or warning) events occur as required. These are real events shown on the status and alarm summary GUI in the top laser table. If a laser equipped telescope does not have priority, it would be required to shutter during a collision event. If a laser equipped telescope has priority, it is not required to shutter. Collision information is shown in the collision table in either case. The LTCS manages all calculations and necessary cleanup following state transitions. Prediction and collision data move between rows on the status GUI depending on whether the calculations are real or simulated as discussed in the paragraph on Preview Mode below.

4.2 Preview Mode

In the first generation LTCS, operators were having difficulty in certain circumstances discovering collisions that would occur at the current position just prior to propagation. The collision would only be detected when the laser equipped telescope began propagation. These collisions are known as "immediate collisions". The reason for this type of immediate collision is that when a laser equipped telescope is "OFF", no calculations are performed (it is unnecessary). As soon as propagation occurs, the calculations begin. For immediate collisions, an immediate shutter command is required. When immediate collisions occur, there is often operator confusion about why the laser failed to propagate, and observing overhead is usually required to recover. To detect and avoid immediate collisions, the operators would run LTCS "hot", meaning that the URL for the laser equipped telescope was modified to always report the laser state as propagating (even when this wasn't the case). This caused adverse side effects, including extra calculation overhead, additional logging, alarming, and unnecessary shutter events. However, these side effects were seen as more desirable than the overhead associated with operations recovery of the AO loop states & observing scripts.

In the second generation LTCS, the need for an "ON" state to address priority resolutions for laser equipped telescopes was leveraged with the query capability to allow for the concept of simulated "previews". These help to discover and prevent some immediate collisions. Preview mode data is not real because the laser isn't propagating. The calculation for possible collisions is done using the underlying query logic, but with the facility's current position (as reported by the URL). This is in contrast to normal queries performed using manual or scripted pointing data inputs. Preview data does not impact current real collisions, predictions, or shutter events. The data is displayed on the Status & Alarm Summary GUI in a separate preview section. As laser equipped telescopes transition states between "ON" and "ON-SKY", the data naturally moves between simulated and real data structures. While not entirely removing the potential for immediate collisions (immediate collisions can occur for other reasons), the operators now see most immediate collisions before going "ON-SKY". This leads to informed decisions for how to react. The only side effect of having preview mode is that previews and queries are mutually exclusive. During a preview, if a query is executed, the preview mode data is temporarily suspended until the query completes. The preview will then resume automatically. The query tool and collector handle internal state transitions and arbitrate modes as required. This is all transparent to the user.

4.3 Slew Detection and Filtering

One of the biggest issues facing daily operations is characterizing an entire site to ensure that all participating facilities adhere to the URL specification. The experience on Mauna Kea has been that several telescopes have not had the resources to automate the setting of the laser impact flag. This has led to some ineffective manual/procedural solutions. A number of shutter events on Mauna Kea have been caused by slewing telescopes. Distinguishing between a slewing telescope and an immediate collision isn't always easy. Staff time is typically required to research collision logs to discover when telescopes haven't met the URL specification. To assist with slewing, detection was added to the collector. The collector can detect and filter (automatically disable a telescope) during *perceived* slews. However, it must be noted that what looks like a slew to the collector may not actually be a slew. There is enough ambiguity in facility implementations of reported new pointing positions, that it is highly inadvisable to set a filter flag without prior dialog with an "offending" facility. The tool is intended to be helpful in characterizing a site, but is insufficient as a "set-and-forget" tool. The authors recommend either a "NONE" setting, or a "DETECT" setting. A "FILTER" setting should only be used as a last resort after confirmation of incorrect behavior, and by direct agreement with a facility.

4.4 URL Overrides

A URL field configuration GUI was provided with the first generation LTCS software. Telescope operators could manually set some URL parameters with the tool. Included were capabilities to set FOV, laser sensitivity, and enable/disable pointing data logging. The recommended mechanism for setting URL fields is for telescopes to do this

programmatically, based upon guidance in the URL spec. Usually, this is easily automated with a combination of telescope and dome track state, guiding state, and instrument FOV knowledge. However, it is acknowledged that in some cases, either for old TCS systems, and/or for lack of resources, this GUI can be useful. Over time, the configuration tool has become used more for override functions than for facility configuration. This is due to the fact that using the tool to turn a telescope's laser sensitivity off has the effect of removing it from calculations.

Operators typically perform overrides in cases of URL setting problems and/or following negotiations during nighttime collision events. When a long duration collision occurs, a call is usually made to the other facility involved in the collision to determine if the facility is really laser impacted, and/or how long they intend to remain on target. Sometimes, permission is given to override the URL allowing the lasing facility to continue observations. To denote an override clearly, these events have a separate yellow indicator on the URL status display. They are also logged.

In the second generation LTCS, laser state overrides have been added, and the underlying override data file is used to support some internal override functions (preview mode and query mode de-confliction). The configuration GUI automatically discerns laser equipped facilities, and only presents this option to laser facilities.

5. ISSUES DISCUSSION

The following sections describe current system issues. These are broken into subsections addressing current development, new site configurations, and operational considerations.

5.1 Development Issues

LTCS has a number of current development needs that have received little or no attention to date. The reasons are varied. In order of perceived importance (to the authors), areas of need include:

1. Laser dither / offset pointing
2. Better collision test tools.
3. Laser beam FOV modeling
4. A non-sidereal motion and/or Az/El model.
5. Isolation of database calls in the code.
6. Installation / configuration documentation

None of the above development issues is perceived as a critical need at this time. Several of these items would make the LTCS easier to use, and/or make availability of data and/or configuration of new systems easier, but they do not prevent sites from using the system effectively. The one cautionary exception is for the case of laser dithering.

For most current sites, lasers are kept on-axis, so the reported pointing source (laser vs. telescope) is not an issue. For facilities such as Keck, where the laser and telescope have independent pointing models, the choice of which pointing to report becomes important. The URL specification does not provide for separate pointing terms of lasers & telescopes. Laser dithering can be handled appropriately, but requires specialized configuration and URL reporting. For laser facilities capable of independent dithering motion, ***laser pointing*** should be reported. The configured error threshold for a lasing facility's FOV should be set large enough to cover the maximum dither angle. In this way, the lasing telescope FOV is protected while all collision calculations between the dithered laser and other telescopes will be correct.

Of the other development items listed, the most desirable feature might be a better collision test tool. The desired tool is one in which a laser and non laser facility interaction can be 'gamed' for particular geometries of interest. Using knowledge of static positions, the laser's dynamic pointing, sodium parameters, and a desired altitude of collision, the tool should produce the telescope's perspective RA, DEC, and Equinox (and/or at least the Az/EL). A current tool exists to "walk" a telescope and laser equipped telescope into collision, but a better tool is desired. Some discussions with Gemini South have occurred on this topic, but to date no tool has been created to satisfy this need.

An issue that will become more important in the next couple of years will be modeling of laser beams as FOVs. Currently, laser beams are modeled as cylinders. This is insufficient for MCAO constellations. This will likely receive some attention as the first LTCS MCAO systems come online.

The issue with non-sidereal and/or AZ/EL mode is that the LTCS is currently built around a dynamic pointing model using RA, DEC, and Equinox pointing. This is not always the most efficient method to report pointing information. During times when telescopes are parked, and/or are tracking non-sidereal targets, the LTCS performs a great deal of unnecessary transformation and prediction calculations. A more efficient method for reporting pointing data in these cases is to report the pointing mode with relevant pointing data. URL specification changes to allow a pointing mode, Az/EL, and proper motion terms would be desired. The LTCS could then model geometry predictions using the appropriate pointing model and terms. The current software can operate without these feature enhancements (albeit with extra calculations and logging). As such, this item has been ignored up to now.

Finally, there are a couple of development issues related to new releases and site configurations. Up to now, only three LTCS configurations have been defined. For each of these, some code tailoring was needed. With additional minor work, some sections of the code could be modified to make code releases and site configurations easier. The amount of work to do this is larger than the typical time to make the needed modifications, so these issues have been ignored.

5.2 Site Configuration Issues

Three LTCS configurations have been defined to date. All three of these were configured using an expert team to include the primary developer and a local site expert. During discussions between Keck and ING, the thought of trying to configure La Palma without a team approach was considered. However, a few factors prompted reconsideration, and a team approach prevailed. These factors include:

1. No LTCS installation manual exists
2. Development / design documentation lags new feature releases
3. Some code *must* be altered for new sites (particularly php screens). In some cases (where the LTCS db isn't MySql), the Status Manager must have modifications to support the database choice.
4. Training and system characterization are much better done on-site.

None of the above issues prevented LTCS from being re-configured for La Palma. In fact, following a collaborative model, the software developers at ING have become experts in their own right. The authors were able to configure a fully working La Palma configuration in less than 1 week. This included all modifications needed to the source code and design discussions resulting in the eventual second generation features. It should be noted that start/stop, monitoring, and alarming scripts (i.e. for URL failures) are not provided as part of the core LTCS software release. However, example start/stop scripts from the Solaris implementation are available for comparative purposes.

Some recent discussions with Gemini South have occurred regarding potential new LTCS sites in Chile. The Chilean sites (Gemini South, SOAR, and CTIO) may attempt to perform their own configurations without assistance. It remains to be seen how well this approach will work. A new site that wishes to do its own LTCS configuration must be prepared for some amount of reverse engineering due to the absence of installation guidance documentation. To set up a site requires configuration files, internal files, operating system paths, database initialization, and code changes. Following this, familiarity with the system is required to characterize and establish correct system operating behavior (all telescopes and laser equipped telescopes working together). The expert teaming model has been employed with great success thus far, and is the recommended strategy for new sites. The authors experience has been that a teaming strategy offers great time and effort savings over a “go-it-alone” approach. If Gemini does proceed with an independent strategy for configuring the Chilean sites, it is possible that installation documentation and/or generic code alterations supporting future configurations may occur that will benefit others.

5.3 Operational Issues

A number of operational issues have been uncovered during the commissioning of LTCS on Mauna Kea. Many telescopes on Mauna Kea are older systems where the TCS is not easily accessible for appropriate automation of URL data, and/or where resource constraints limit new development to achieve desired system behavior. A significant effort has been put into discovering telescopes that slew while claiming sensitivity to laser emissions. Telescopes are free to implement their own solutions to providing pointing updates, and this sometimes leads to inconsistent reporting and/or a need for analysis of odd system behaviors. Similar issues with oversized FOV settings have been discovered on Mauna Kea. Manual / procedural solutions for setting system parameters have not worked as well as automated solutions, but even some automation has functioned incorrectly. Work with facilities to improve overall system behavior continues. It is interesting to note that parameter setting issues are not constrained to telescope facilities. With multiple laser facilities now in operation on Mauna Kea, a similar set of issues has occurred with inconsistent setting/reporting of laser state, pointing data, and running of LTCS system processes. Lessons learned now should benefit all sites in the future.

A significant operations issue to be resolved in the near future is how to shift towards a “first-on-target” priority scheme. How well this idea will be received within the astronomical community is unknown. Active astronomy using lasers enables the full spatial resolution of large telescopes, but operational ramifications are yet to be fully analyzed. It is expected that this paradigm shift will require operational procedural changes, additional training, staff resources, and possibly additional tools before a fully satisfactory outcome is achieved. While some initial dialog between lasing facilities on Mauna Kea has occurred, involvement of many telescope facilities will be required before all issues can be addressed. La Palma will likely play a leadership role in this regard, having the first site in a “first-on-target” scheme.

Finally, there is a need for additional system/site testing. With three configurations at two current sites, and 20 participating telescopes in the baseline, LTCS will likely receive needed tests over time. A detailed test with Subaru has been conducted[10]. A preliminary test with Gemini occurred in 2005, but the results were inconclusive. Additional Mauna Kea tests are in planning stages. A similar pattern of testing will likely occur on La Palma as GLAS matures. Future sites must be prepared to allocate resources to validate the static and dynamic positional data being provided by each telescope into the model to ensure the system behaves as expected.

6. CONCLUSIONS/LESSONS LEARNED

The collaborative effort between the W. M. Keck Observatory and the Isaac Newton Group, to work a second generation LTCS system for use on both Mauna Kea and La Palma, has brought benefits beyond each group’s unique laser programs. The teams have made significant LTCS improvements using the talents and experience in both groups.

The second generation LTCS is much more capable than the first generation LTCS system. It can accommodate a wide variety of configurable priority schemes, support multiple laser equipped telescopes, and has query and preview tools to allow for better operations. The new features provide better support for mixed ELT/non-ELT site configurations, and can support both classic and queue scheduled operations.

The original priority rule developed for Mauna Kea required only laser equipped telescope facilities in a configuration to be aware of LTCS functions. For new/future priority schemes (first-on-target types), *all* facilities are required to be *fully* aware of LTCS system behavior. Operations procedures, LTCS training, and the possibility of additional tools may be required before full satisfaction is achieved. For both telescopes and laser equipped telescopes, their multi-million dollar investments can easily be thwarted by poor facility URL implementations. It remains to be seen how well facilities will be able to work together to transition towards both an “active” astronomy paradigm, and achieve efficient operations under a variety of LTCS priority schemes.

A number of minor development, operations, and configuration issues exist. None of these prevent LTCS from being effectively reused. Two primary development issues are a lack of a nice collision test driver tool, and a need to eventually model MCAO laser constellations as FOVs. The operational issues are a continuing need to characterize LTCS site behavior to ensure facilities provide correct URL data, a need for site testing, and a need for effective coordination (political and technical) during the transition to “first-on-target” priority schemes. The issues associated with configuring new sites are primarily a lack of installation documentation, and a need for LTCS system expertise during initial setup and system characterization.

Mauna Kea's use of LTCS is maturing to a point where the primary issues are operational. By far the most significant operational issue seen thus far has been the need to work directly with facilities to ensure understanding of URL system parameters and correct reporting. As a result of a loose initial coordination strategy and typical resource constraints, overall site behavior has not been as efficient as it could have been. Some operational difficulties may have been avoided with better coordination and/or centralized management. The experience on Mauna Kea suggests that a functional system can be obtained with loose coordination. However, maximizing science potential at a site likely requires a mix of LTCS system expertise, policy guidance, oversight/monitoring, and potentially some enforcement

LTCS is finding reuse beyond Mauna Kea and La Palma. Discussions with Gemini South have already begun. Additional (preliminary) discussions for LTCS configuration at SOAR and CTIO have begun as well. As with the initial configuration of Mauna Kea and La Palma, configuration of the new Chilean sites may require some expertise to help setup and establish efficient system operations.

The LTCS code base has been made generally available to the astronomical community with a simple licensing agreement. Contact the primary author for additional details.

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