SLR2000 Software: Current Test Results and Recent Developments

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Abstract:

Much of the SLR2000 software has been tested by using software simulators, prior to having the full SLR2000 system hardware available. This has allowed us to check the predictions, test the decision making processes, verify the inter-computer communications, make use of the remote terminal, and ensure that the entire data path works properly. Especially important to test by simulation are the decision making processes of the Pseudo-Operator (POP). Results of this testing are presented here along with details of recent additions to the SLR2000 software capabilities and a status of the software development effort.

Overview

SLR2000 is designed to be a completely autonomous Satellite Laser Ranging System. The software must not only interface to the hardware and collect ranging data, but it must also make all of the decisions concerning what to track, when to track, and when there are problems that require help. The six SLR2000 computer subsystems that perform these functions are:

- Interface and Control Computer (**ICC**) - DOS on Pentium II
  - interfaces to mount, ranging electronics, and star camera
- Dome Control System (**DCS**) - DOS (microchip controllers)
  - controls the dome position and shutter
- Pseudo-OPerator (**POP**) - LynxOS on Pentium (embedded VME)
  - automates operator function
- Data ANalysis computer (**DAN**) - LynxOS on Pentium (embedded VME)

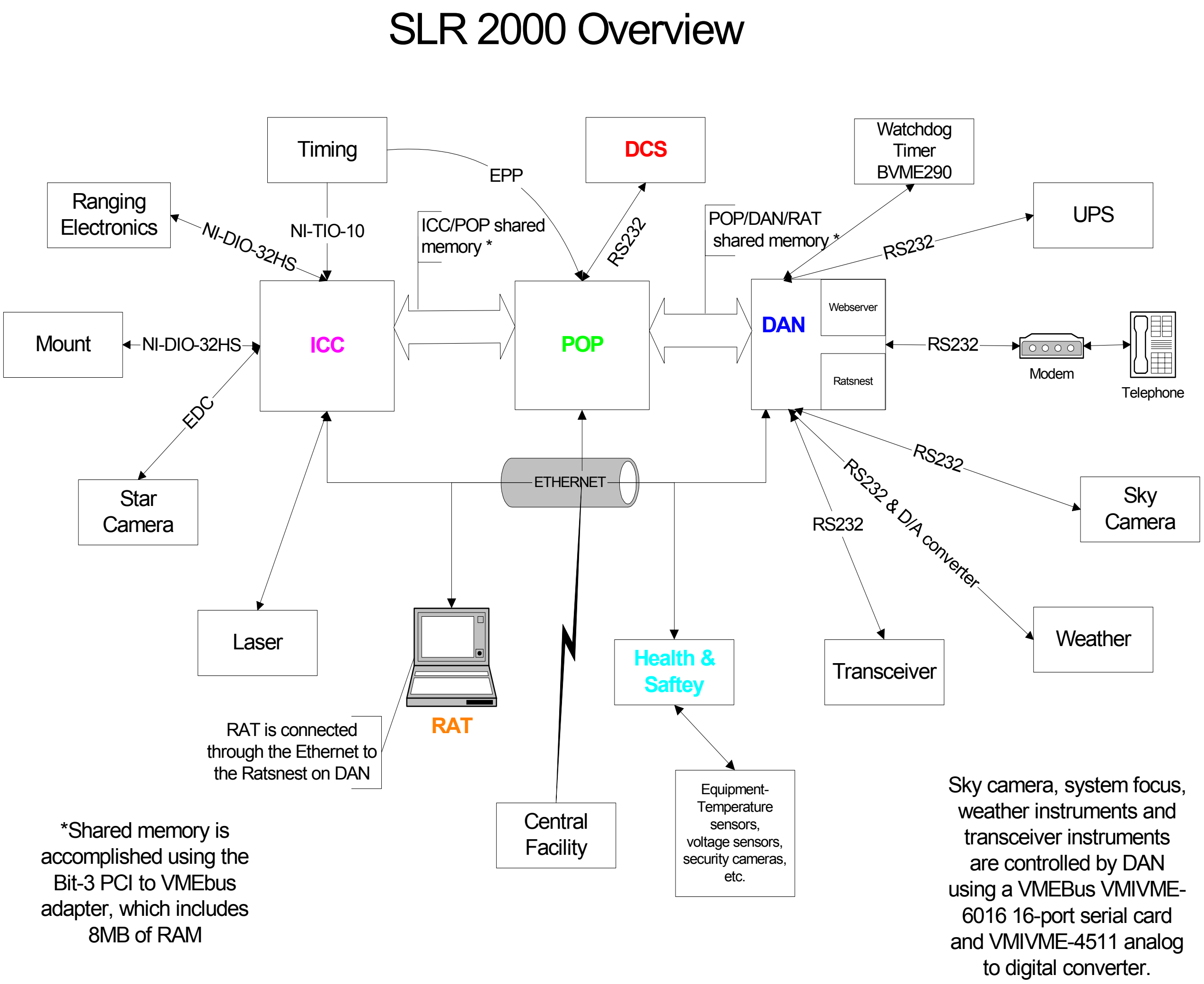
- provides post processing, non - realtime hardware interface, and web site

- Health AND Safety (**HandS**) - Windows NT on Pentium II (Compact PCI)
  - monitors system health and interfaces to security system

- Remote Access Terminal (**RAT**) - Linux (currently Pentium II laptop)
  - provides interface to SLR2000 for humans (direct or remote)

Figure 1 is a block diagram of the SLR2000 computer system, showing how each subsystem interfaces with the rest. The color code for the computers will be used throughout this paper.

The design and development of this software package has been reported at previous Laser Ranging Workshops [McGarry 1998, McGarry 2000] so we will limit our discussion here to the recent developments and test results. For a complete overview of the SLR2000 system see [Degnan 2002] in this Proceedings.



RAT is connected through the Ethernet to the Ratsnest on DAN

*Shared memory is accomplished using the Bit-3 PCI to VMEbus adapter, which includes 8MB of RAM

Sky camera, system focus, weather instruments and transceiver instruments are controlled by DAN using a VMEBus VMIVME-6016 16-port serial card and VMIVME-4511 analog to digital converter.

Figure 1: SLR2000 Computer System Overview

Interface and Control Computer (ICC)

All of the ICC interfaces to the hardware subsystems, excluding the laser, have been tested. The following interfaces are installed, system tested, and working: the Xybion mount, EDC star camera, the National Instruments Timing Interface and the Bit-3 PCI to VME interface. The following have been subsystem tested, but have not been tested in the operational real-time software: Honeywell Range Gate Generator, Honeywell Event Timer, and the Photek Four Quadrant Photomultiplier (4QMCP) which was tested at 1.2m telescope.

The simulation software to allow system level software testing of the complete SLR2000 software package has been written, tested, and used. Included in this is simulation of star images in the camera, mount movement, and satellite and noise returns.

Dome Control System (DCS)

The dome interface is checked out and working under POP control. The dome tracks up to 20 degrees / sec smoothly. The shutter control (open/close) must be installed and tested, but the parts are in-house and the software is written.

Pseudo-Operator (POP)

POP performs the prediction and decision making for star calibrations, ground calibrations, and satellite tracking. Most of the software is written and has been tested to the extent possible with our limited access to the hardware system as a whole. System testing to date has been possible only through the use of simulation software which is described below. The following software is considered complete until we can test with actual hardware: timing, scheduling, tracking decisions based upon weather, dome control, star assessment (to optimize system on a star), star calibration control and analysis, prediction calculations, signal processing, and data logging. What still needs to be completed is the satellite point-ahead, choice of secondary targets when the primary cannot be found, use of the cloud camera information, calculating the settings for the transceiver optics, and laser interface decisions (such as blanking time after laser fire). More details on recent testing and software development can be found in the sections following.

Data Analysis System (DAN)

The calibration and satellite data processors and databases, acquisition data generation software (downloading and processing orbit predictions), data delivery system, watchdog timer software, and task scheduling are all developed and undergoing testing. Recent work includes development of a preliminary S2K website (see Figure 2 below), conversion of the normal point software from FORTRAN to C (with an upgrade of the noise rejection algorithm), development of both star calibration and weather databases, and generation of database and disk management routines.

The SLR2000 databases are designed to maintain information onsite for use by the analysis software as well as available for viewing over the website. The database management routines keep the database from growing indefinitely by archiving and then purging the data after a user defined time (nominally 2 years). The disk management routines check the disk space, execute disk cleanup routines if a certain percentage of disk usage occurs and send warning messages.

Other recent activities in the DAN software include the development of the realtime interfaces to the weather instrumentation and sky camera (see Mallama 2002 in this Proceedings), and development of the transceiver interfaces. More detail on this last subject is given below.

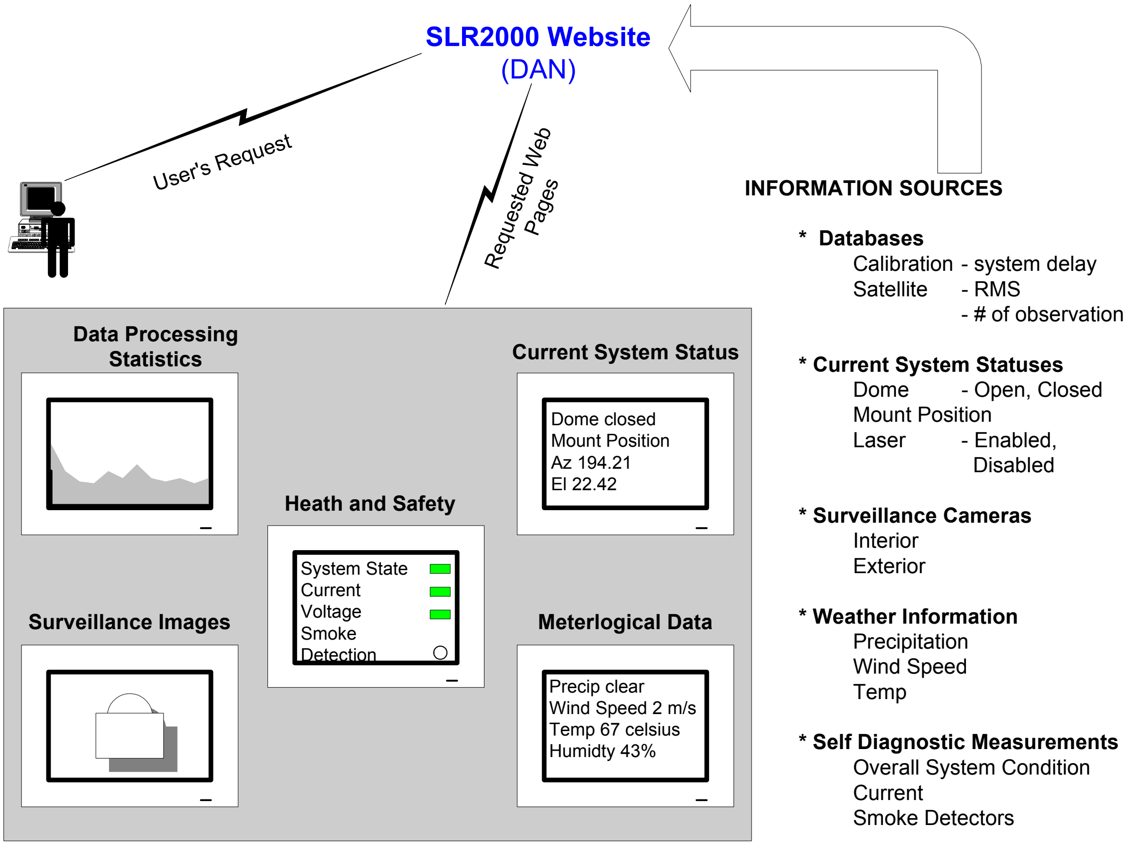


Figure 2: SLR2000 Website

Health and Safety System (HandS)

The Health and Safety system is designed to monitor the state of the entire system, including the facility (main power, heat and cooling), environmental conditions (interior climate conditions, intrusion detection, physical damage), and electronics racks and interfaces (battery backup power, power strips, equipment status). The information is gathered and is used, along with weather information and system performance, to determine tracking status of the system. The status is relayed to the Central Facility periodically and immediately if an emergency condition exist. The Health and Safety system also commands and controls the system's security cameras.

Remote Access Terminal (RAT)

SLR2000 gives developers and maintainers of the system access to data, control, and overrides through the Remote Access Terminal (RAT), a separate laptop computer running LINUX and X Windows. The RAT software system is composed of a data server and command interpreter program called Ratsnest residing on DAN and a GUI display and operator control program named Ratgui residing on the laptop. These communicate via sockets and do not need to be co-located. In fact,RAT could be at a facility far from the SLR2000 station.

RAT has several purposes. First, it provides real-time text display of crucial data from other SLR2000 computers. As Figure 3 shows, this includes time, telescope position, range, various corrections, dome position, SLR2000 subsystems' status, and meteorological information, It also provides after-the-fact plots of ranging data and star calibration results as well as camera images. In its role as system controller, RAT allows the user to initiate certain activities such as a star calibration or override various control variables such as time, mount offsets, and range biases. RAT was designed as a debugging and diagnostic tool and will not be used during normal autonomous operations.

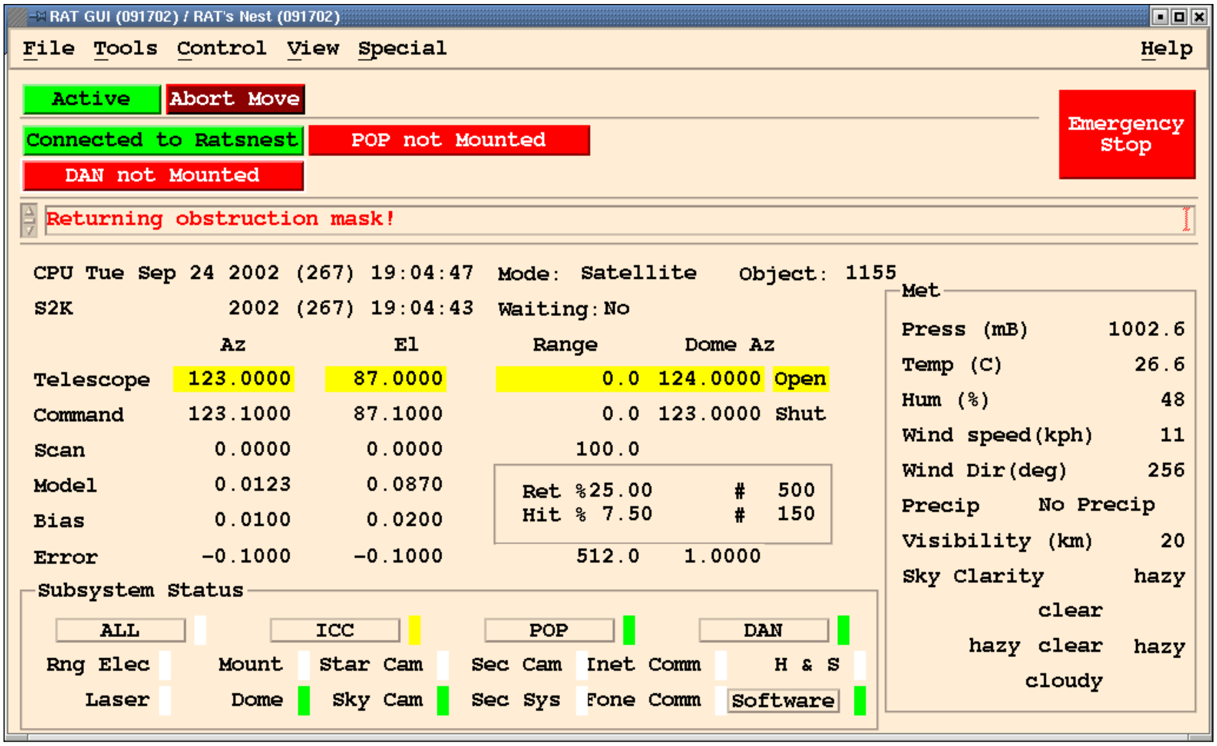
In the last couple of years, several features and refinements have been added to the RAT software. Ratgui now provides a complete diagnostic dump of all fields in shared memory. This is a dynamic dump so that changes to data fields appear on the display window immediately. Among other things, this display gives confirmation that commands from Ratgui are having the desired effect down-stream.

Histograms and computed offsets from the quadrant detector are now displayed in pop-up windows. These displays will provide sanity checks of the performance of the detector and the auto-guiding software.

In addition to the star camera images, the IR sky camera images can now be displayed on demand. As shown in Figure 4, the images are displayed in pseudo color with the interior of the circle showing the sky as reflected in the convex full-sky mirror positioned below the downward-facing camera.

Since the SLR2000 telescope and mount are not always available for tests, we must be able to simulate them. When doing these simulations, it is necessary to introduce a control or “truth” mount model which produces mount positions that are not “perfect.” Then star calibration and satellite tracking software can be tested for their ability to deal with an imperfect mount. Ratgui now allows the user to select mount model “truth” from an existing file, zeros, or typed-in values.

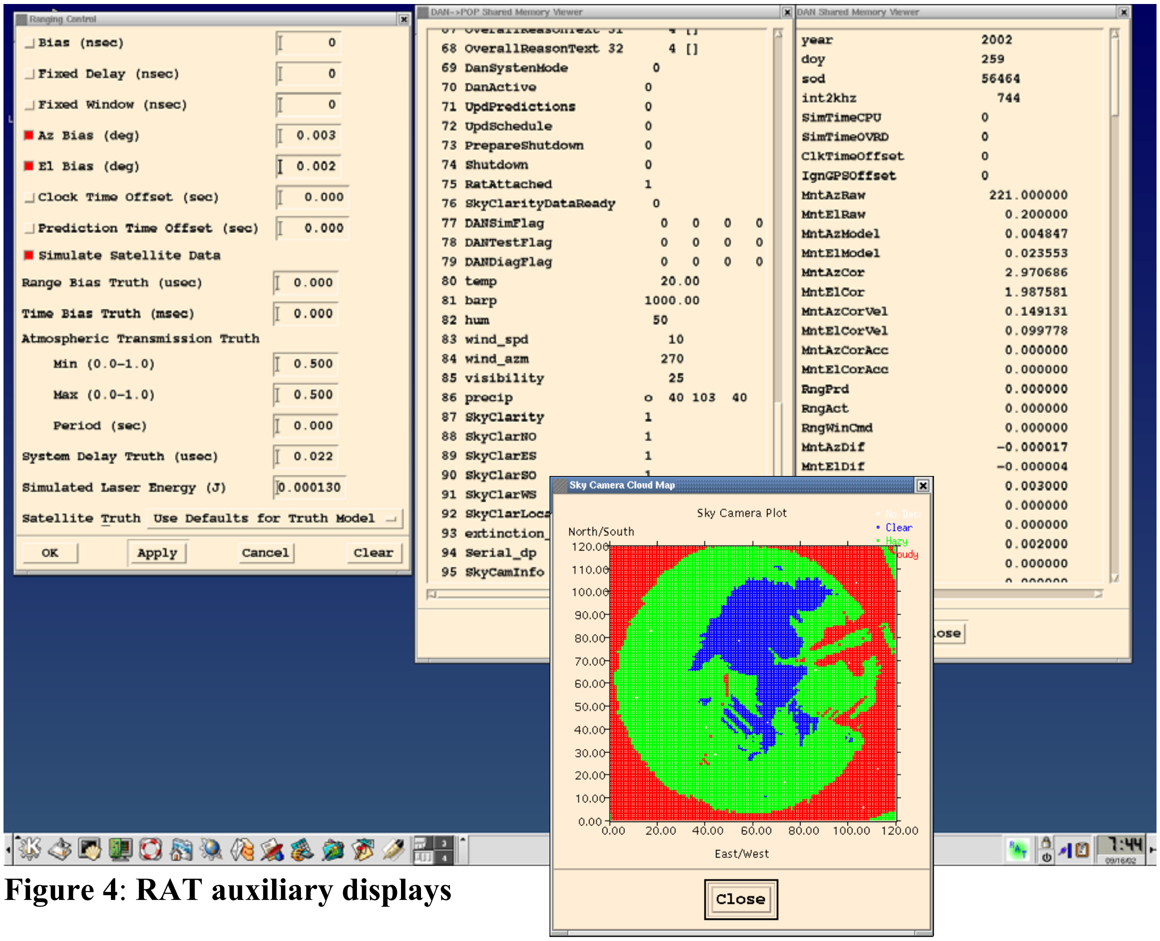
The Ratgui/Ratsnest combination has now demonstrated the ability to control star calibrations, ground target ranging, and satellite passes by overriding the preset schedule. As designed, RAT provides a means of conducting hardware and software tests and provides valuable feedback for assessing system performance. RAT has been used to test the automated scheduling, star calibrations and the corresponding analysis, satellite tracking (including searching for and acquiring the target), and the proper response of the system to error conditions.



```
Returning obstruction mask!

CPU Tue Sep 24 2002 (267) 19:04:47   Mode:  Satellite    Object: 1155
S2K         2002 (267) 19:04:43   Waiting: No

                 Az           El         Range      Dome Az
Telescope    123.0000      87.0000         0.0  124.0000 Open
Command      123.1000      87.1000         0.0  123.0000 Shut
Scan           0.0000       0.0000       100.0
Model          0.0123       0.0870
                                      Ret %25.00       #   500
Bias           0.0100       0.0200    Hit % 7.50       #   150

Error         -0.1000      -0.1000       512.0    1.0000
```

```
Press (mB)         1002.6
Temp (C)             26.6
Hum (%)                48
Wind speed(kph)        11
Wind Dir(deg)         256
Precip          No Precip
Visibility (km)        20
Sky Clarity          hazy
              clear
        hazy  clear  hazy
             cloudy
```

Figure 3: RAT main display



```
☐ Bias (nsec)                           0
☐ Fixed Delay (nsec)                    0
☐ Fixed Window (nsec)                   0
■ Az Bias (deg)                     0.003
■ El Bias (deg)                     0.002
☐ Clock Time Offset (sec)           0.000
☐ Prediction Time Offset (sec)      0.000
■ Simulate Satellite Data
Range Bias Truth (usec)             0.000
Time Bias Truth (msec)              0.000
Atmospheric Transmission Truth
    Min (0.0-1.0)                   0.500
    Max (0.0-1.0)                   0.500
    Period (sec)                    0.000
System Delay Truth (usec)           0.022
Simulated Laser Energy (J)       0.000130
Satellite Truth  Use Defaults for Truth Model
```

```
68 OverallReasonText 32      4 []
69 DanSystenMode              0
70 DanActive                 0
71 UpdPredictions            0
72 UpdSchedule               0
73 PrepareShutdown           0
74 Shutdown                  0
75 RatAttached               1
76 SkyClarityDataReady        0
77 DANSimFlag                 0    0    0    0
78 DANTestFlag                0    0    0    0
79 DANDiagFlag                0    0    0    0
80 temp                      20.00
81 barp                    1000.00
82 hum                        50
83 wind_spd                    10
84 wind_azm                   270
85 visibility                  25
86 precip                    o  40 103  40
87 SkyClarity                1
88 SkyClarNO                 1
89 SkyClarES                 1
90 SkyClarSO                 1
91 SkyClarWS
92 SkyClarLoc
93 extinction_
94 Serial_dp
95 SkyCamInfo
```

```
year                2002
doy                 259
sod                 56464
int2khz               744
SimTimeCPU          0
SimTimeOVRD         0
ClkTimeOffset       0
IgnGPSOffset        0
MntAzRaw             221.000000
MntElRaw               0.200000
MntAzModel             0.004847
MntElModel             0.023553
MntAzCor               2.970686
MntElCor               1.987581
MntAzCorVel            0.149131
MntElCorVel            0.099778
MntAzCorAcc            0.000000
MntElCorAcc            0.000000
RngPrd                 0.000000
RngAct                 0.000000
RngWinCmd              0.000000
MntAzDif              -0.000017
MntElDif              -0.000004
                       0.003000
                       0.000000
                       0.000000
                       0.002000
                       0.000000
```

Figure 4: RAT auxiliary displays

RECENT TESTING: Simulated Satellite Tracking

At the Matera Workshop we presented our design for star calibration and satellite tracking tests using simulations, and showed results from star calibration simulation tests [McGarry 2000]. We have recently also tested satellite tracking using simulations.

During operational tracking POP computes the predictions and outputs the commands to the ICC to control the mount and ranging electronics. The ICC collects the range return data and passes it back to POP who then stores the data in a circular buffer, extracts the signal from the noise, determines the pointing and ranging corrections, and logs the data. Figure 5 shows the operational data flow.

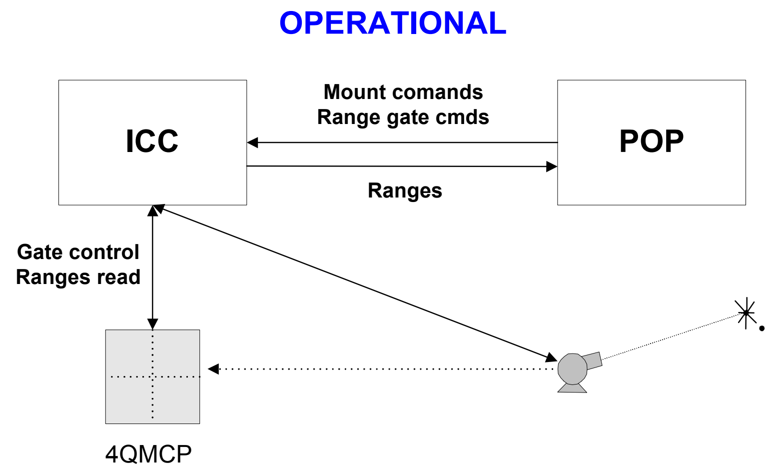


Figure 5: Operational System Block Diagram

In simulated tracking and ranging POP continues to perform the same operational functions. In fact the operational software on POP is unaware that the data is being simulated. Special software on POP which runs independently from the operational part calculates the information needed by the ICC to simulate the mount and the ranging returns. The ICC interacts with the operational part of POP normally, thus allowing the software on POP to be tested. An operator controls the simulation parameters from RAT. Figure 6 shows the simulation test scheme.

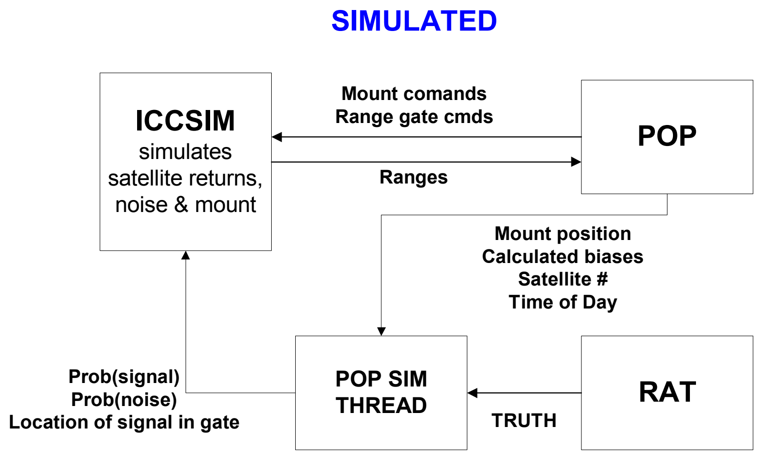


Figure 6: System Block Diagram during Simulations

We have been able to test both ground calibrations and satellite tracking, including checkout of the circular buffer, signal processing, bias determination, target search and acquisition, reporting of the data in Shared Memory (for RAT) and logging and analysis of the data.

Figure 7 below shows results from a ground calibration where all of the returns within the range window are plotted (noise and signal). Initially the calibration target is not within the receiver field of view and the system must move the mount to search for the target. Figure 8 shows the mount biases as the system searches for the target using a spiral scan in azimuth and elevation.

Once signal is found (line visible to eye in range plot), the software uses the information from the four quadrant detector to center the target in the FOV.

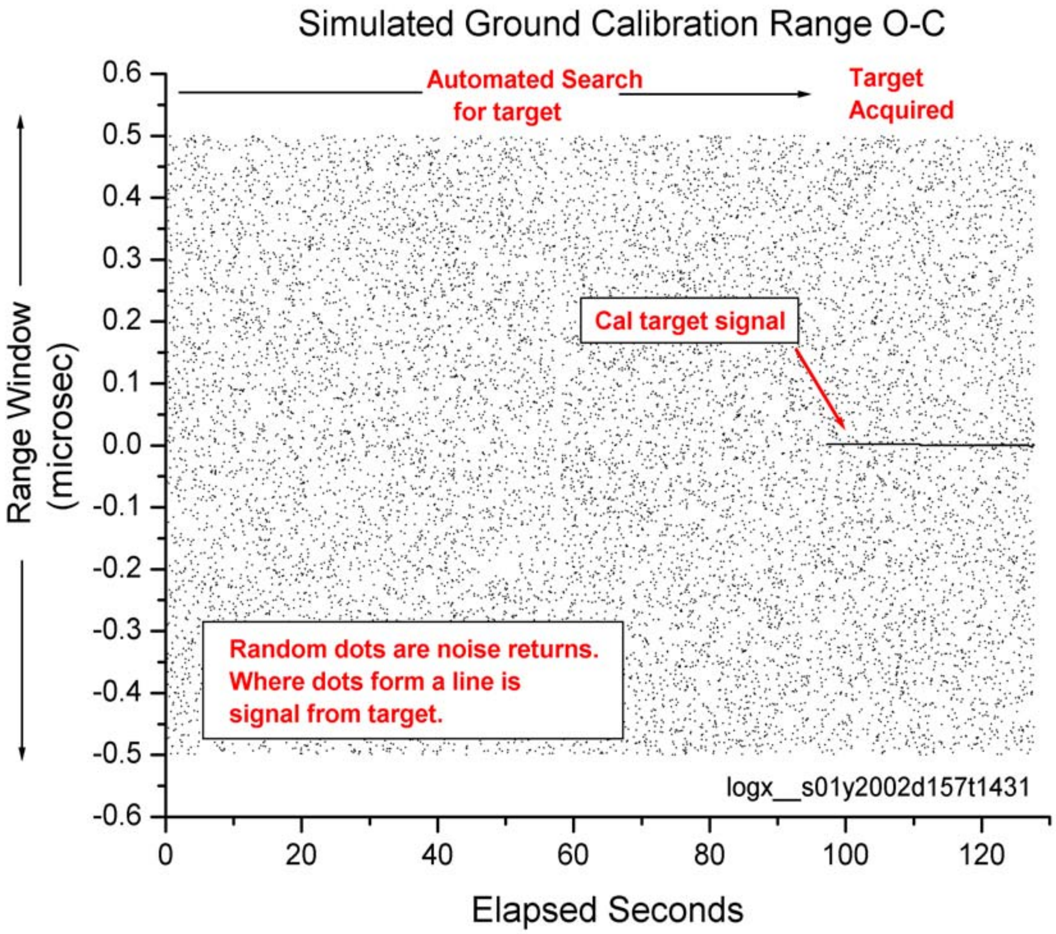


Figure 7: Range O-C Plot for Simulated Ground Calibration

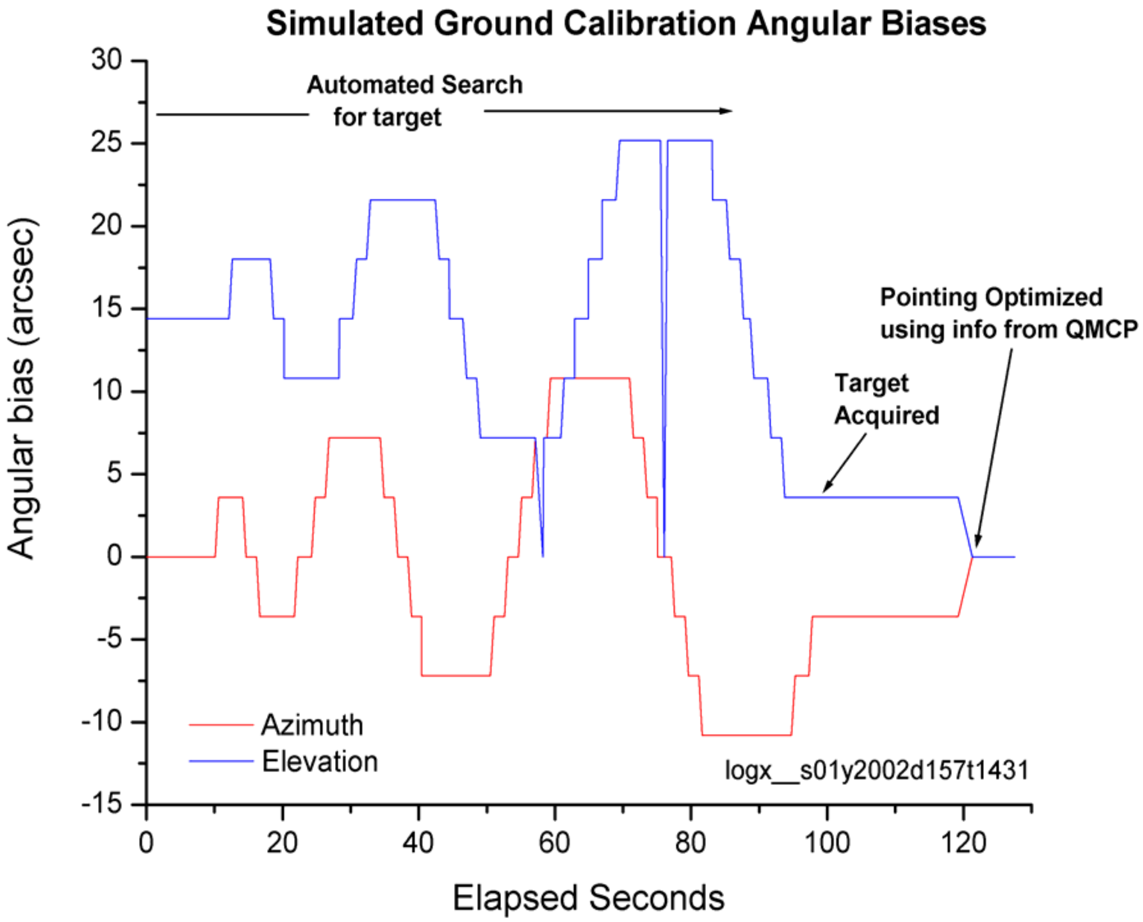


Figure 8: Automated search for ground target, followed by optimization of biases using QMCP information once the target is found.

RECENT TESTING: GNP Residuals of a Simulated LAGEOS-2 Pass

To verify the SLR2000 simulator and the capability of the SLR2000 data software packages, a test was performed by simulating SLR2000 raw range data for a 6/4/2002 Lageos-2 pass based on HTSI prediction data. These raw ranges were fit with the SLR2000 data processor, generating ILRS full-rate observations and residuals. The SLR2000 Generic Normal Point Processor was then used to produce ILRS normal points. Passing the data through a Lageos-2 4-day GEODYN solution, ILRS full-rate and normal point data residuals were generated for this pass. The pass residuals were offset from the long arc solution by approximately 1.3 meters. Because the data was generated from prediction data, this offset from 0 is attributed to an acceptable level of prediction bias. The simulated pass was verified to be good, and demonstrates that the data flow from prediction to logging appears to be working well. Figures 9 and 10 show the results of this analysis.

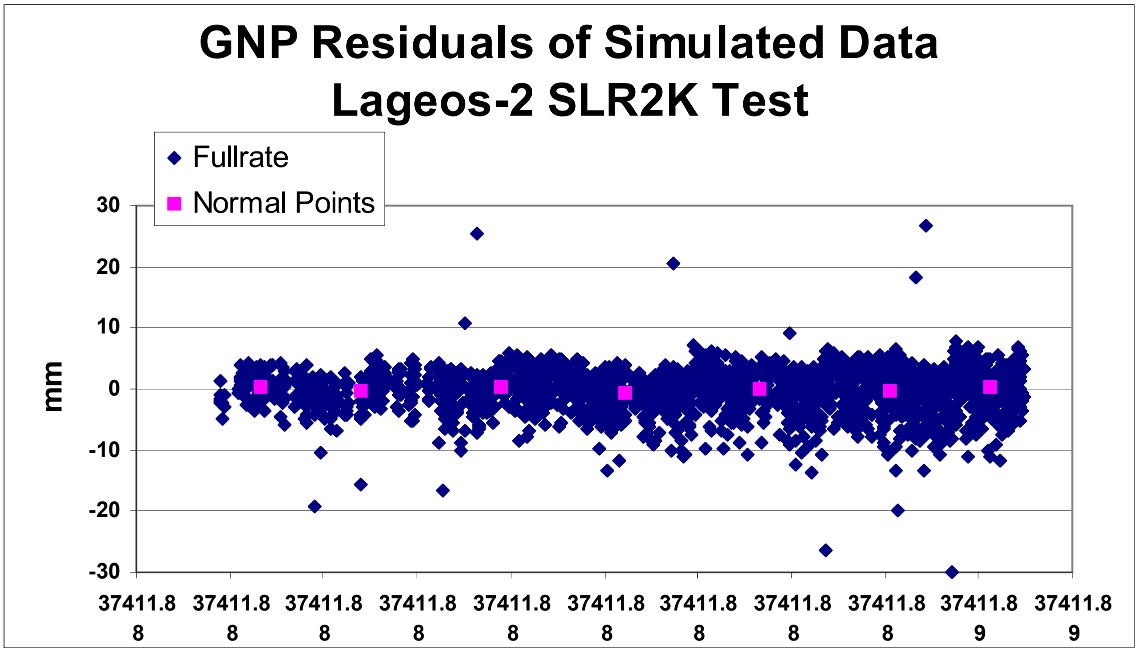


Figure 9: Residuals of Normal Point data from a simulated pass.

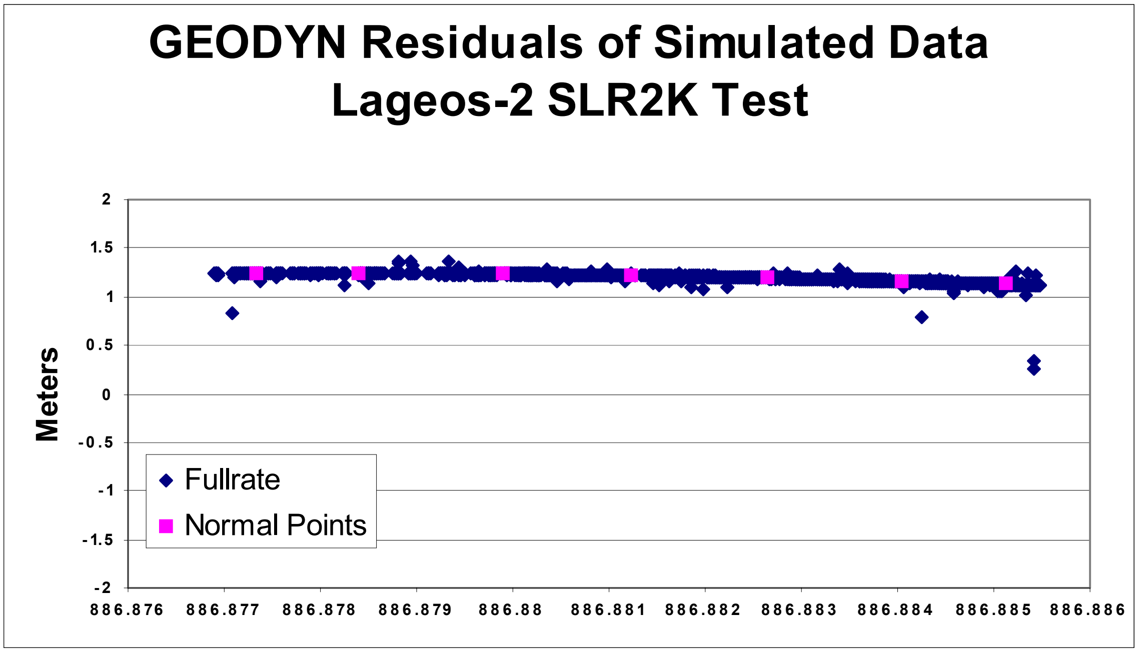


Figure 10: Residuals of SLR2000 simulated data plotted against actual laser data. The offset of the simulated data from real data is indicative of the bias in the predictions.

RECENT DEVELOPMENTS: Developing the Transceiver Optics Interface on DAN

The six motorized stages used for positioning optics on the transceiver are shown in the following table.

Linear or Rotational	Laser or Detector Path	Optics
Linear	Detector	Field lenses and apertures
Linear	Detector	Day/night/twilight filters
Linear	Both	Clear/blocked/ND5 filters
Linear	Both	Adjustable beam divergence
Rotational	Laser	Point ahead, Risley prism #1
Rotational	Laser	Point ahead, Risley prism #2

All devices are controlled by a MicroMini serial device. Prior to operation the device must be initialized and the ‘home’ position established by moving the stage to a physical limit of motion.

The linear stages move various filters, lenses and apertures into position. The rotational stages contain beam deflecting prisms. When programmed in combination these prisms produce a beam deviation of variable magnitude and direction. This allows the laser beam to be transmitted in a direction ahead of the target, to account for light travel time, and to allow the telescope to be separately pointed in the direction of the return beam.

Figure 11 shows the diverging lens (intentionally blurred) during an exposure made while its stage was in motion.

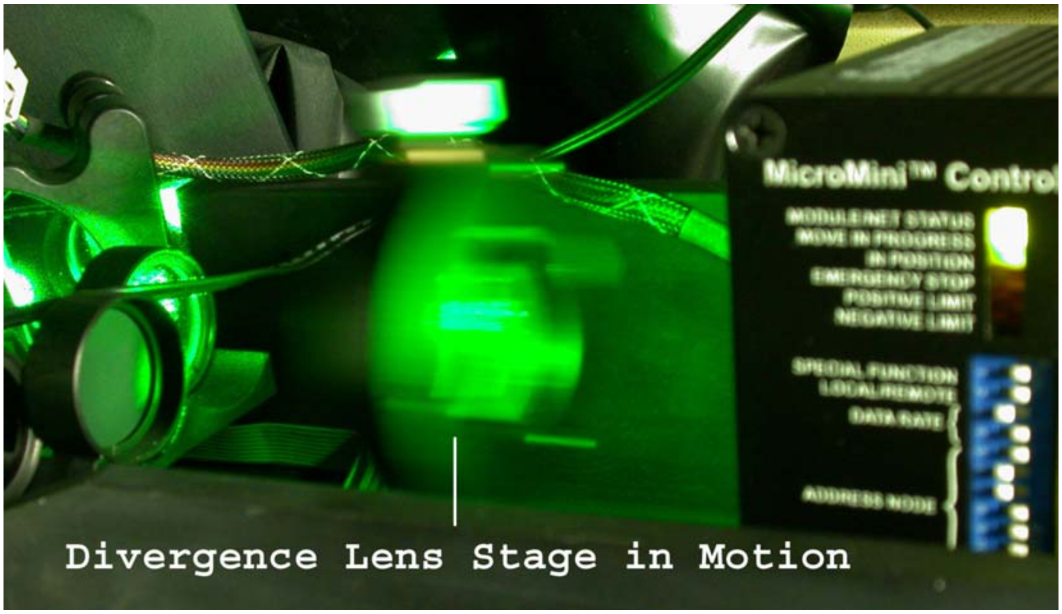


Figure 11: Transceiver Motorized Controller

RECENT DEVELOPMENTS: Adding Sun Avoidance to POP

The purpose of the sun avoidance module is to prevent the telescope from pointing within 15 degrees of the Sun, so that direct sunlight can not enter the tube. A baffle covering the front window of the telescope rejects sunlight outside of this radius.

The 15 degree condition must be met at all times, whether the telescope is tracking, moving from one satellite to another, or sitting still. At the same time, the software allows tracking and calibrations to proceed without significant delays. The fundamental decisions are based upon the queries in the following table.

Logic question	**Operational response**
Is the telescope pointed within the Sun avoidance region (this is a 'fail safe' condition) ?	Immediately slew away from the Sun.
Will the telescope pointing enter the Sun avoidance region if it remains on its current heading ?	Compute an alternate slew around the Sun avoidance region.
If the target is inside the Sun avoidance region, will it remain there for a long period of time ?	If 'no' wait for target to emerge from avoidance region; if 'yes' inform the pseudo operator.
Is the Sun at least 2 degrees below the horizon ?	There is no danger from the Sun; any slew is permitted.

Figure 12 illustrates the sun avoidance situation where the direct route from the end of one pass to the beginning of another would cause the telescope pointing to traverse the avoidance region. In response, a 'safe' slew is ordered which causes the pointing to proceed outside of the circumference of the avoidance region.

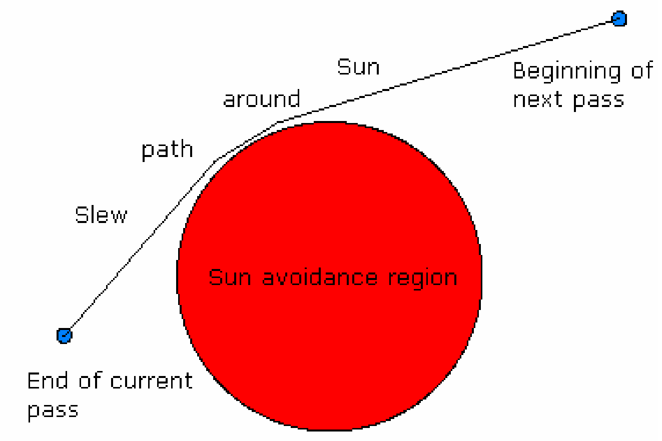


Figure 12: Sun avoidance path

Summary

The SLR2000 software package is ready now for star calibrations, and the team is working toward being ready for satellite tracking in the coming months. We have tested as much of the system as we can without available hardware by simulating the hardware. This has allowed us to successfully perform fully automated simulated star calibrations, and also successfully search for, acquire, and track simulated satellites without any operator intervention.

Predictions are automatically downloaded and the schedule generated daily. Normal points are also automatically calculated and data transferred to the central facility hourly.
We can remotely control what is being tracked and can control (to some extent) the course of the track by entering bias, and changing how the track is performed using RAT.

We estimate the coding to be about 90% complete (excluding Health & Safety).

We are currently in the process of upgrading all of the computer hardware because (1) it is obsolete, and (2) it is not able to satisfy the current NASA Information Technology (IT) security requirements. This work goes on in parallel with the software testing. Lastly we are adding a seventh computer to the system to host the website which should provide a more secure environment than our original plan of hosting it directly on DAN.

References

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