TELESCOPES, STATIONS AND UPGRADES SESSION SUMMARY

Chair: Craig Smith

The session on telescopes, systems and upgrades demonstrated that the field of satellite laser ranging (SLR) is healthy and growing. Speakers during the session described a wide range of new and refurbished SLR instruments all over the globe.

Probably the most ambitious project described came from the Russian Federation where 6 new SLR systems have recently been completed and there are plans to build up to a further 15 stations by 2010, all in support the upgraded Glonass Global Navigation System (GNS).

Not to be outdone, we heard from NASA and US Contractors about a revitalized SLR program that has returned a number of stations to operations (TLRS3 and 4) as well as maintenance and development of the MOBLAS network. SLR 2000 development has also been continued.

Not to be outdone by Russia or the US, China too has entered a new era of significant SLR development as contributions to the Galileo GNS has spurred on rapid SLR activity in this country too. Excellent presentations were provided about a new SLR station built in San Juan, Argentina, as well as significant upgrades to existing stations at Yunnan, Changchun and Shanghai SLR Observatories.

SLR work however, is a global enterprise and from France we heard that after 30 years of operations the old SLR station (7835) at Grasse has been decommissioned. This station has been replaced by new and more capable systems FLTRS and MEO, whilst the old telescope will find new life as an SLR telescope in Matjiesfontein, South Africa. Plans were also presented for new SLR network in South Korea.

We look forward to hearing about the progress of all these ambitious projects and exciting developments at the next ILRS workshop.

Grasse laser stations in evolutions to future and technological developments

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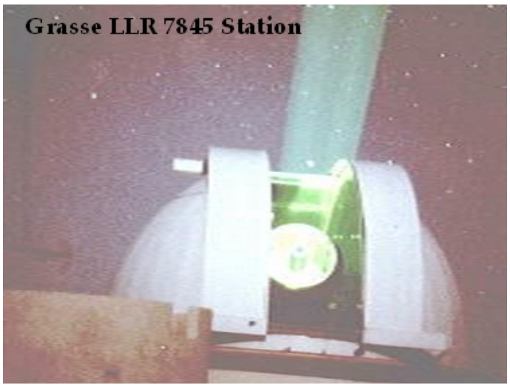
Abstract

A very important project in term of buildings and technology for telescopes, mount and dome has been started at the Grasse Observatory since September 2005.

A new laboratory has been built in place of historical SLR fixed station (7835) to receive mobile SLR system (FTLRS) for upgrade, development and operations between field missions.

The current LLR station (7845), renamed MeO (for Metrology and Optics), is being completely rebuilt to track and range in the future from "Low Earth orbiting satellites" to the Moon and even further to support new missions in the solar system. The project status will be reported in this presentation with both technological issues and new potentialities for such installations at Grasse.

Introduction and short report 1980-2005 period



The Grasse LLR system with a large and accurate 1.5 meter telescope got first moon returns in 1982.

In this configuration (0.2 Hertz ruby laser with 3 nanoseconds pulses), 1166 normal points have been acquired in 5 years with an RMS of about 20 centimeters.

In 1987 a major upgrade was achieved on this system with a new Yag laser (10 hertz-300 ps pulses) and timing system (Dassault event timer).

During this very operational period, about 8500 npts (65% of the global network) were acquired with an rms of 3 cm and a stability at some millimeters level.

The station stopped in summer 2005 for new developments described below in this paper.

This very efficient SLR system installed at Grasse observatory in 1975 at 30 meter from the LLR system tracked in thirty years about 35000 satellites passes.

The quality and quantity of data over the years of this core station is very impressive and scientific community can thanks a lot observers, engineers and scientists involved in this process very consuming in term of manpower.

The station stopped definitively his activity in summer 2005 to involve laser staff in new evolution for SLR/LLR activity.

Historical SLR station definitively stopped, waiting South Africa collaboration

In September 2005, telescope and mount were dismantled and temporarily installed in the old trailer waiting new future abroad.

In fact for some years, South African colleagues are promoting an LLR/SLR development for this country in collaboration with global scientific community.

OCA/CNES/GRGS proposed to participate to this venture in putting this one meter telescope at South African geodesists disposal. Of course the mount and mechanical devices of this system will have to be refurbished (encoders, drive motors, coude mirrors etc.) and a budget is already planned by this partner for renewing this telescope/mount at HartRAO.

In the context of this interesting project in South Hemisphere a new site has been found in a very favorable place for SLR/LLR activity in term of meteorological conditions. We can see here on the next photo, this future site for Space Geodesy Observatory near Matjiesfontein at about 250 km north of Cape Town and 70 km south of GFZ Geodynamics Observatory and South African Astronomical Observatory.

After some administrative agreements in progress, OCA 1 meter telescope/mount should be shipped to South Africa before summer 2007.

Future site for Space Geodesy Observatory in South Africa **1 meter Telescope/mount in trailer at OCA in 2006**

New laboratory for FTLRS developments and operations built in place of old telescope :

Just in the place of old one meter telescope, we built a new laboratory perfectly suited to host mobile system between fields campaigns.

The configuration of the setup has very original features.

The group laser /mount /telescope is installed on a platform elevator with two possible positions:

-One down in the laboratory to achieve technological developments tuning and maintenance in good conditions (left picture).

-The other one 1.40m higher (right picture) with the roof open and the telescope able to view the sky and to achieve operations on satellites in normal conditions with operator control facilities inside the building.

The reference point of the station in high position has been designed to be very stable and repetitive at better that one millimeter level. In this observation place, the station is no more supported by but lie on a metallic square embedded in the roof concrete, such a way the platform can be down in this phase**.**

For the campaigns setup the group laser/mount/ telescope is took off from the special support fixed on the elevator in the laboratory and installed in the tripod which can be easily packed for shipping and deployed on site to the concrete pad.

Ftlrs in campaign configuration – Ajaccio 2005

New devices (electric jacks software controlled) to easily adjust leveling in automatic mode have been developed. This new facility is very important to assist local observers with remote control capability during outside campaign.

LLR Station renamed to MEO and completely rebuilt

In summer 2005 we stopped temporarily the old LLR station in order to modernize and to imply it in more goals (science programs and technology).

This important project in term of funding and manpower implied for design and buildings had been prepared for three years with detailed technical studies and looking in the future for emerging new projects on next 20 years.

The main idea is to have flexibility in different configurations :

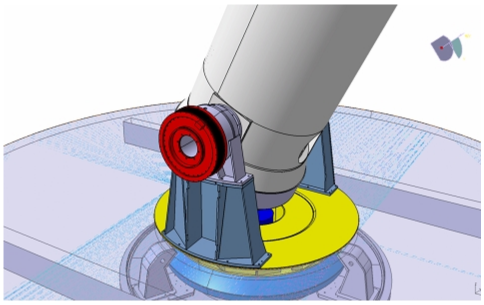
- **A new generation of Laser Ranging station**
  – From 400 km to the Moon
  – One Way Interplanetary mission
  – Highly Automatic
- **Research & Development facility**
  – New optical links
  – Time transfer experiments
  – One Way Interplanetary missions
  - Detection, Event Timer

A. Telescope/mount

In the future, the mount will be able to have a speed compatible with SLR on lower satellites and this is a very strong constraint on such an heavy system.

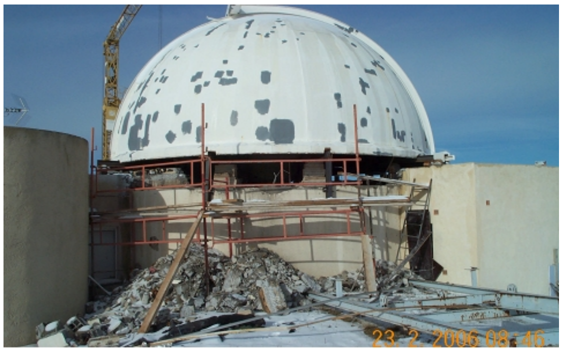
We decided to install in this new design powerful and precise direct torque motors on the axes in such a way to have speed multiplied by an important factor .

Nevertheless, the pointing accuracy remains an important challenge especially to range moon and future spacecrafts in solar systems.



The quality of the encoders installed on the axes and the mechanical stability of the whole setup are been carefully designed and should lead to an absolute pointing accuracy below 1 arc second.

B. Dome



Similar constraints are applied on the dome and in order to remain compatible with mount speediness a lot of modifications are today achieved.

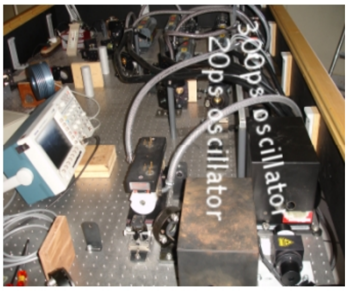
This dome is twenty five years old today and at this occasion the Observatory workshops undertook heavy maintenance works on metallic structures to hope reliable operations in future.

C. Laser and focal laboratories

To track both moon and HEO satellites, two lasers systems in different rooms were operated the past years (Quantel with 300ps and BMI with 20 ps).

A very important work and new design have been achieved to combine both lasers on a single bench with three capabilities

- 800 mJ in 10ns at 10 Hz
- 250 mJ in 300ps at 10 Hz
-250 mJ in 14 x 20ps at 10 Hz



The last configuration with 14 pulses of 20 ps is a very original design to range the moon very accurately comparable with current SLR systems and achieving a return rate similar to previous configuration (single pulse of 300 ps).

In future, at least **3 focal laboratories** will be installed under the telescope to have different R&D experiments and routine operations accessible with a fast and easy mirror switch on the coude.

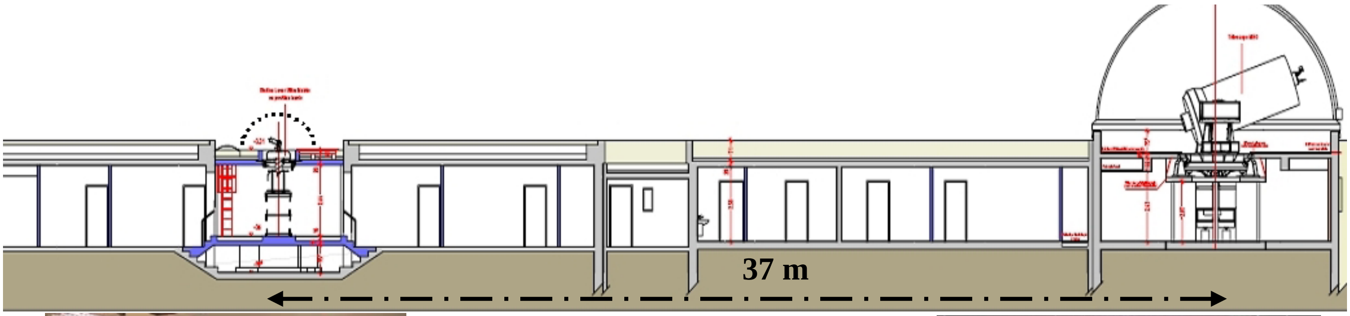
Conclusion

- **SLR fixed station (7835) stopped in june 2005**
  - 30 years of fruitful operations
  - Telescope and mount moved in the trailer waiting eventual collaboration abroad

- **New laboratory build in this place for FTLRS**
  - Two position capability with elevator system and opening roof
    - Technology developments
    - Operation on satellites to Lageos.

- **Old LLR Station renamed to MEO and completely refurbished.**
  - Earth satellite capability 800 to 36000 km Moon reflectors.
  - R&D studies and new experiments (Time transfer, transponder…).

- **New SLR facilities in 12/18 months**
  - Two observing systems (0,13 and 1,50 m telescopes) occasionally collocated.
  - Fields campaign for FTLRS (maximum 6 months/year).



New Russian Systems for SLR, Angular Measurements, and Photometry

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Abstract

A brief description is presented of two novel-type stations providing satellite laser ranging, angular measurements, and photometry (in reflected sunlight), recently developed in the Institute for Precision Instruments Engineering (IPIE). Putting the stations in operation will expand the Russian Laser Tracking Network to six stations.

Compact station

The compact station with two 25-cm diameter optical systems (the first one used for transmission/reception of laser ranging signals, and the second one for angular measurements and photometry) has the following design features:

- The weight of any single unit of the system (in package) does not exceed 50kg, with system total weight less than 300kg. Thus, no special lifting mechanisms are needed for installation.
- An autonomous cover for the optical unit and mount allows installation on a small pier, without erection of a special fixed tower.
- Low power consumption (≤2.5 kW) allows supply from single-phase mains or from a portable power generator.
- Low cost in serial production (about 750K USD) and simple technology provides manufacturing by existing industrial firms.

Compact Laser/Optical Station Parameters

SLR of spacecraft with retroreflectors

- Spacecraft orbit height range: 400 to 40000 km
- Daytime and nighttime measurements for spacecraft with orbit heights 400 to 6000 km
- NP RMS errors 0.5 to 2 cm (averaging interval 60 s)
- Residual (systematic error) 0.5 to 2 cm
- Elevation range 20 to 85 deg.

Angular measurements

- Visual star magnitude: $\leq 12^{m}$
- RMS error for spacecraft angular velocity up to 40 arcsec: ≤ 2’’

Photometry

- Visual star magnitude: $\leq 10^{m}$
- Brightness determination error: $\leq 0.2^{m}$

The option for mounting on a fixed position has a weight of 170 kg (optics + mount). No lifting mechanisms are needed for installation. The station has been tested near the 6-

meter telescope of Russian Academy of Sciences (in Northern Caucasus) during 2005. Currently, serial manufacturing is organized of the compact station for the Russian Laser Tracking Network. It is planned to produce 15 stations more until 2010.


Figure 1: *Compact SLR station in operation*

Mobile Station

The mobile station is placed into 3 containers installed on wheels for transportation. The weight of optics and mount units is 12 tons. Except this unit, the system comprises an equipment container with operator's workplace, as well as a "house" for operator's rest. The mobile station acceptance tests have been completed on the Russian cosmodrome "Baikonur" in Kazachstan.

Pointing/tracking system and mount of the compact station

Mount parameters

- Mount type: Az-El, with two flanges for equipment mounting
- Digitally controlled torque motor drive
- Equipment weight on each mount flange:≤ 20 kg
- The mount is provided with an autonomous cover
- Angular rotation range:
    - Elevation: 5 to 95 deg
    - Azimuth: -278 to +278 deg
- Maximum angular speed 30deg/s;
- maximum angular acceleration 30deg/s^2

Mobile laser/optical station parameters

SLR of spacecraft with retroreflectors

- Spacecraft orbit height range: 400 to 40000 km

- Daytime and nighttime measurements for spacecraft with orbit heights 400 to 6000 km
- NP RMS errors 0.5 to 2 cm (averaging interval 10 s)
- Residual (systematic error) 0.5 to 2 cm
- Elevation range 20 to 85 deg

Angular measurements

- Visual star magnitude:≤ 14^{m}
- RMS error for spacecraft angular velocity up to 40 arcsec:≤2”

Photometry

- Visual star magnitude:≤ 12^{m}
- Brightness determination error: ≤ 0.2^{m}

The mobile station with a 60 cm diameter receive telescope and two separate optical systems for laser beam collimation and TV camera, has the following basic parameters.

Station of both types have similar laser ranging system with the following parameters:

Operation wavelength.. 0.532 μm
Pulse repetition rate .... 300 Hz
Laser pulse duration .... 250 ps
Laser pulse energy.. 2.5 mJ
Output beam divergence .... 5 arcsec
Receive telescope diameter
– compact station .... 25 cm
– mobile station .... 60 cm
Timing accuracy (measurement position on time scale) .... 200 ns

***Figure 2**: Operation site with installed equipment (containers and telescope)*

Figure 3: Mobile station preparation for operation

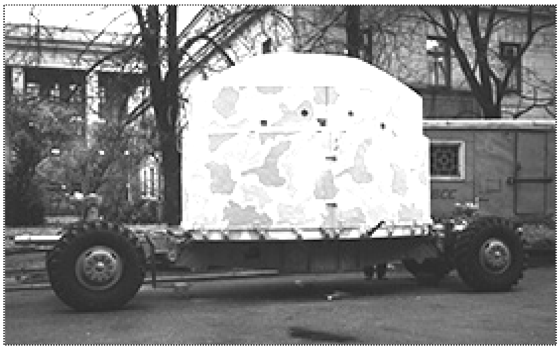


Figure 4: Mobile station during transportation

Figure 5: Mobile station in operation

Figure 6: Mobile station operator workspace

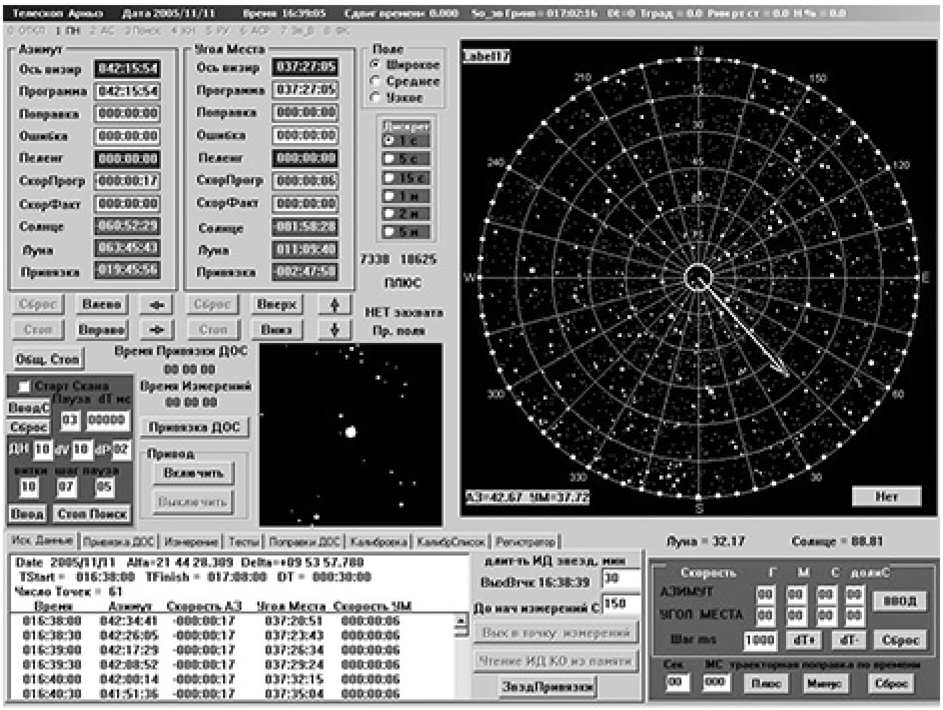
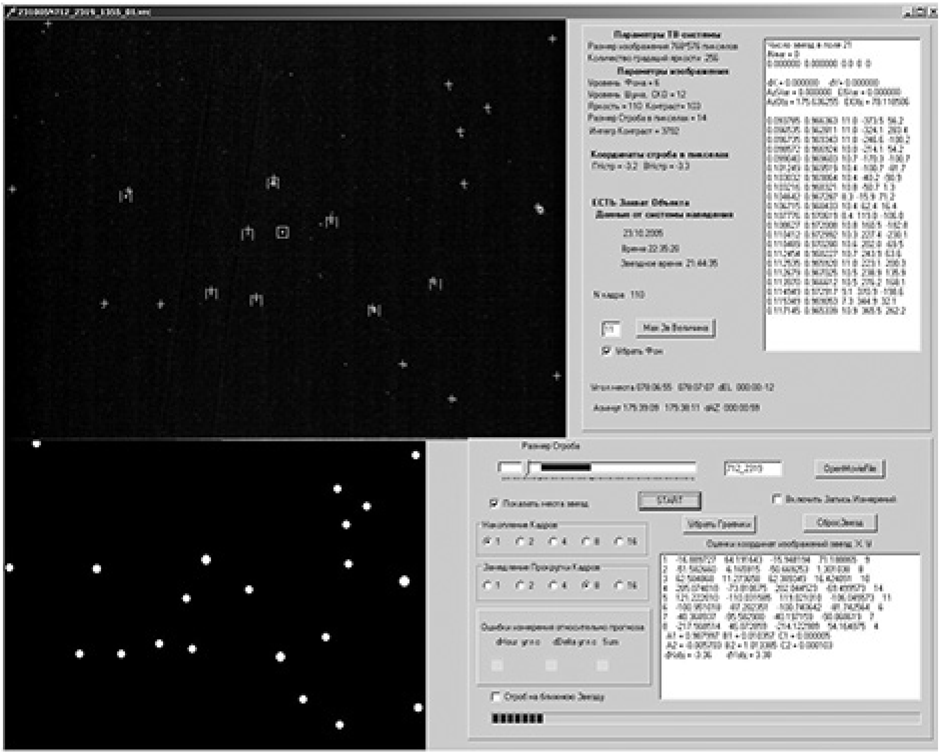


Figure 7: Versatile pointing/tracking control virtual panel

Right: image of star catalog.

Center: image of calculated catalog star positions in the TV camera field of view (around the telescope pointing direction).



Upper left: TV frame with GLONASS-712 spacecraft in the center.

Lower left: **star** catalog fragment. + marks: position of catalog stars in the TV frame.

II marks: star tracking gates (stars selected for spacecraft angular position measurements).

Figure 8: *Versatile angular measurement (astrometric) virtual control panel*

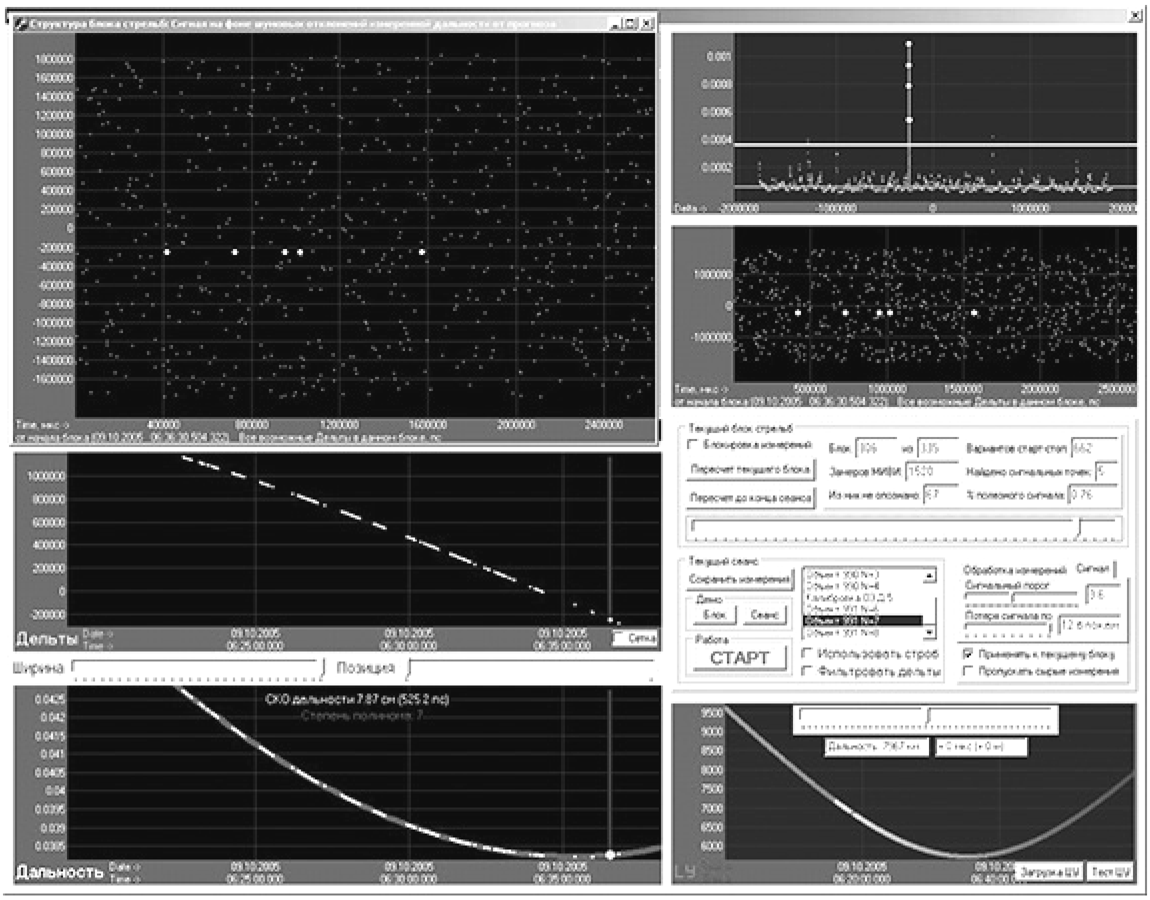


Figure 9: *Laser ranging control virtual panel (daytime observation of LAGEOS)*

TLRS-3 Return To Operations

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Abstract

The Transportable Laser Ranging Station 3 (TLRS-3) tracked from the Arequipa, Peru site for almost twelve years when the station was decommissioned in January of 2004. Replacing the SAO-2 in 1992 in a partnership between NASA and the Universidad Naciaonal De San Agustin, the TLRS-3 had travelled between Cerro Tololo, Chile and Arequipa, Peru after beginning its first operations in 1988 visiting the Mojave site in Goldstone, California. This paper will discuss the repairs, upgrades, and modifications accomplished at the TLRS-3 as well as the results of the first data collected.

History of TLRS-3 in Arequipa, Peru

The TLRS-3 replaced the SAO-2 system as the primary tracking station in Arequipa, Peru on August 7, 1992 with the tracking of an ERS-1 pass. In an agreement between NASA and the Universidad Naciaonal De San Agustin (UNSA), UNSA provided the operational crew while HTSI provided engineering support. TLRS-3 operated very well for almost twelve years until NASA budget reductions necessitated the closing of TLRS-3. On January 27, 2004 TLRS-3 tracked its last pass, a Starlette. In the fall of 2005, NASA tasked HTSI to return TLRS-3 to operational status. The UNSA crew returned to the station on December 12, 2005 to begin the task of reinitializing the system. HTSI working, with NASA and UNSA, began restoring the TLRS-3 to full operations, returning to the station in January 2006. The task of returning TLRS-3 to operations was done concurrently with the TLRS-4 Return to Operations effort.

TLRS-3 Return to Operations Strategy

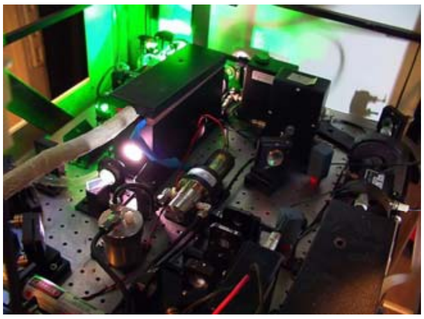
With the TLRS-4 Return to Operations effort preceding the TLRS-3 effort by a few months, the TLRS-3 effort was able to take advantage of the multiple enhancements, upgrades and repair strategies used to quickly bring TLRS-4 back to operational status. Unlike the TLRS-4 though, the TLRS-3 had been without power and had not seen any type of maintenance for two years. Scheduled for TLRS-3 would be a full system inspection, implementation of the software and hardware improvements made to TLRS-4, a full system characterization using the System Operational Verification Test (SOVT) process, and a full validation of system performance prior to release of data to the ILRS.

Significant Engineering Issues

The TLRS-3 was off line for over 2 years with no HVAC control, no humidity control, and no air filtration. The system had not been exercised in any way. As a result the integrity of the station computers, system electronics, telescope optics, laser system, and gimbal were of concern. With the lack of humidity control, corrosion issues were of concern as well, especially with the wire wrap boards, ICs and IC sockets, connectors, switches, etc. and the metal surfaces within the system, especially the laser. Because of the uncontrolled atmosphere within the trailers, temperature cycling presented a connection issue with wire wrap boards, connectors, etc. also. Maintenance of the site and main power system had not been performed either.

Planned and Implemented Upgrades

Upgrades planned for the TLRS-3 had already been implemented and proven to the TLRS-4. The Upper Deck received several enhancements to reduce maintenance and improve lifetime of the optics, improve the accuracy of the star calibration and reduce the time required to accomplish the calibration, and to improve throughput of the daylight filter. The optical system of the entire Upper Deck was enclosed to assist in keeping the optics clean, improve daylight tracking, and provide additional operator safety. A camera system was installed to increase the accuracy of the star calibrations. The optics layout was also redesigned so that optics did not have to be removed to perform the star calibration and so that the laser and star image could be easily co-aligned. The 10 angstrom daylight filter was replaced with a unit that has a 68% throughput and is quite temperature stable. The telescope was returned to NASA SLR Engineering in the USA and was completely disassembled, inspected, cleaned, and realigned. Throughput increased from ~ 50% to 87%. The T/R Switch was upgraded to an improved stepper motor design which was much more temperature stable than the old design. The Photek MCP Upgrade was installed replacing the failing ITT MCP. The upgrade included a newly calibrated CFD as well. The Controller Computer received improved Sattrk and Monitor programs. With these improvements came the Window/Window Upgrade, Mode Change Bias Reset, enhanced “Record All frames” function, 5pps and 4pps Thread Matching and Automated Switching, Sun Avoidance, Horizon Mask, the new Go/No Go software, and the high voltage power supply scaling upgrade. The new TLRS-4 microprocessor based Trackball was installed as well. Maintenance to site power was performed which included refurbishing the site power transformer.



Current Status

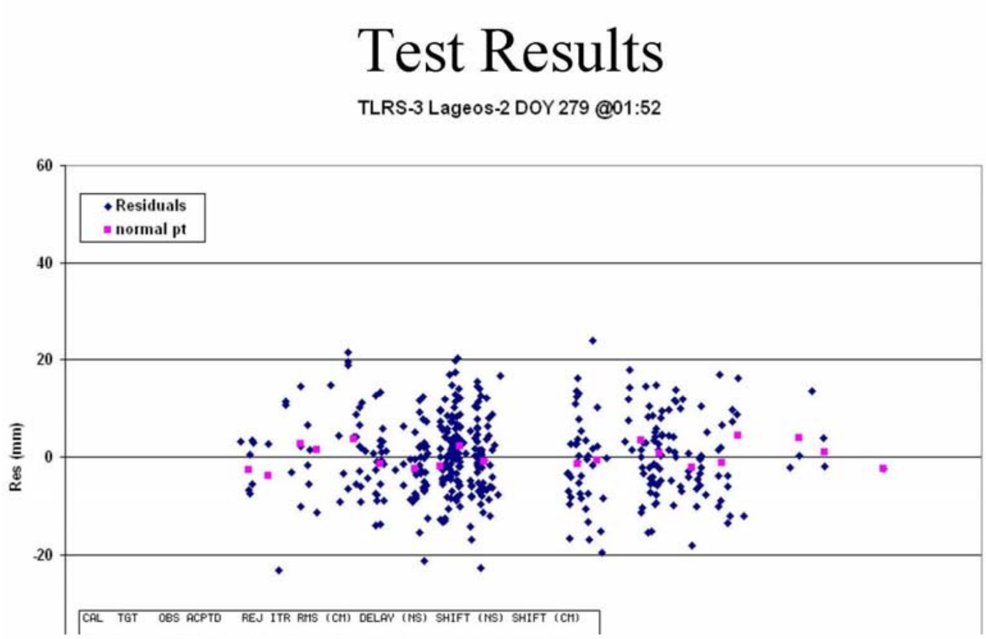
The TLRS-3 is producing high quality data. Over 90 pass segments have been acquired with a data quality of <10mm RMS on Lageos and Starlette and <20 mm RMS on Ajisai. CHAMP and Grace B have been tracked. Average ground calibration is excellent at the 5.4 mm level.

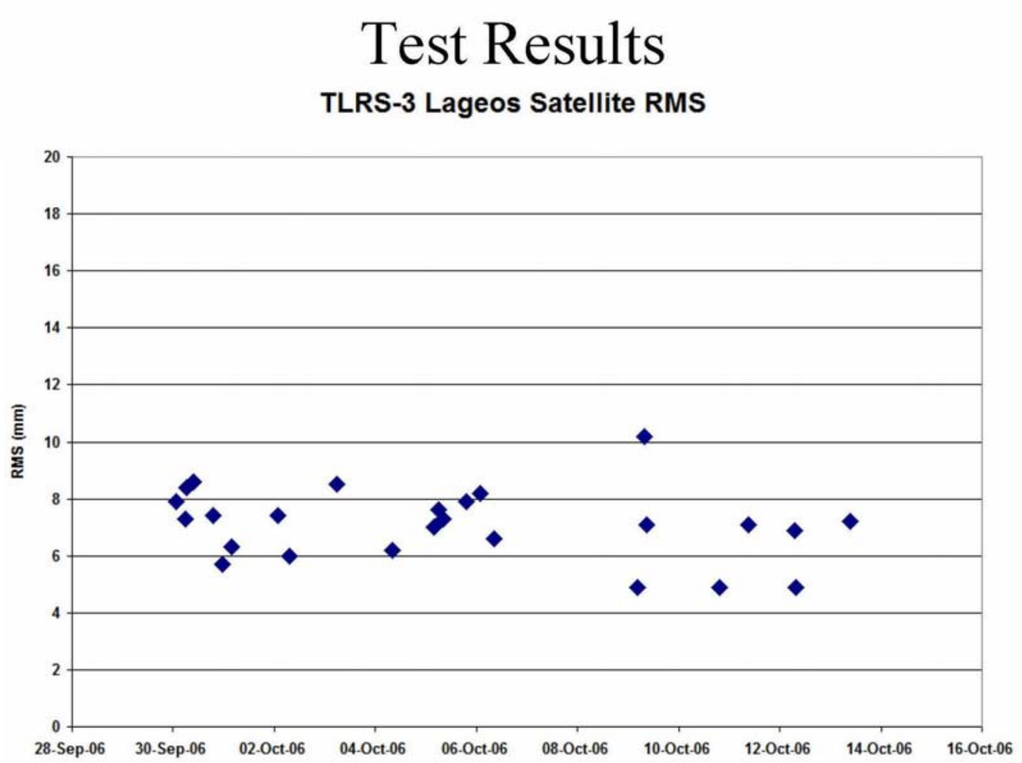
Future Plans

Though significant progress has been made in bringing the TLRS-3 back to operational status, there are still some unfinished tasks. Optimization of gimbal tracking performance, completion of the 4pps upgrade, completion of the Controller and Processor software upgrades and testing, calibration of system test equipment, restocking of system spares, completion of a site safety inspection and the performance of the site survey.

Test Data

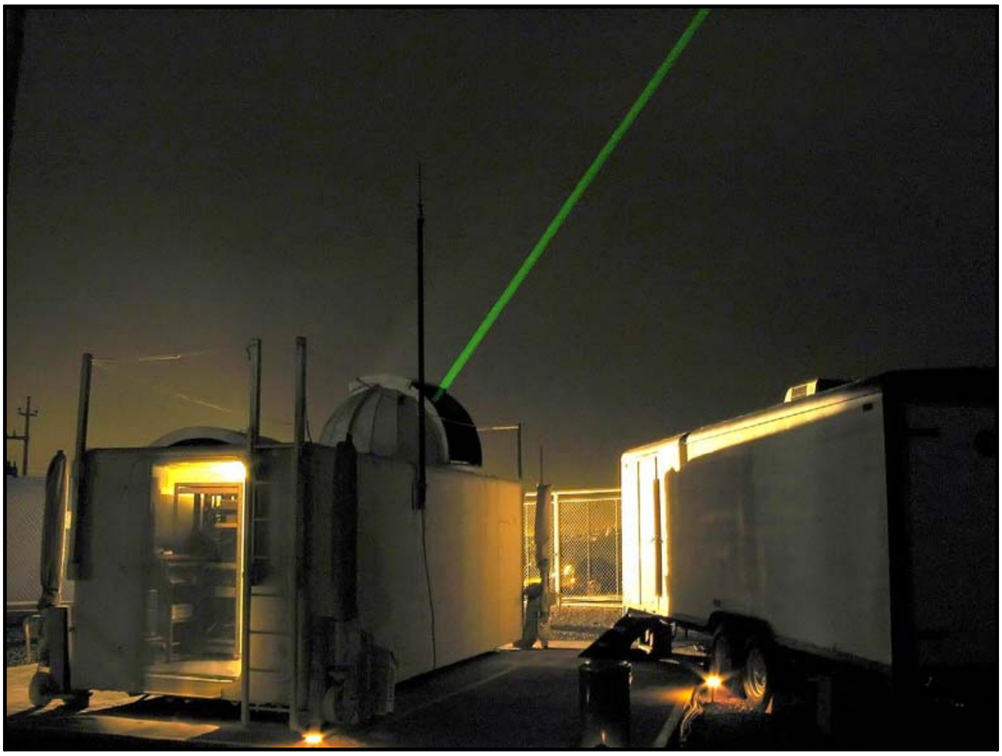
Graphical examples of the Lageos satellite data and a listing of all the passes acquired by TLRS-3 during the upgrade are provided below. Included in the pass listing are calibration RMS, satellite RMS, system delay shift, calibration observation count, and satellite observation count.





Test Results

PASS DATE	OCC NUM	SATID	TARGET	TARGET DISTANCE	# CAL OBS	# CAL REJ	CAL RMS (mm)	APPLIED DELAY	SHIFT (mm)	# SAT OBS	# SAT REJ	SAT RMS (mm)	MEAN TEMP ©	MEAN PRESS (mbars)	HUMIDITY (%)	NUM NP DATA BINS	NUM NP
29-Sep-06 00:53	03	1500	BC	105981	1948	14	4.5	3637.2	-1.07	93	15	22.2	13.32	761.2	51	30	18
30-Sep-06 01:21	03	5986	BC	105981	2188	9	5.9	3643.9	6.16	92	0	7.9	12.31	760.5	46	4	4
30-Sep-06 01:43	03	4378	BC	105981	2188	9	5.9	3643.9	6.16	19	6	4.2	11.73	760.6	45	28	6
30-Sep-06 02:03	03	1500	BC	105981	2188	9	5.9	3643.9	6.16	341	23	17.3	11.57	760.7	45	20	19
30-Sep-06 05:51	03	5986	BC	105981	2046	5	6.4	3643.5	-1.46	10	0	7.3	10.27	759.7	43	2	2
30-Sep-06 06:11	03	1155	BC	105981	2046	5	6.4	3643.5	-1.46	224	1	8.4	10.29	759.5	42	13	13
30-Sep-06 06:56	03	317	BC	105981	2034	4	6.4	3644.6	0.65	343	23	14.2	9.88	759.5	41	27	19
30-Sep-06 08:05	03	1134	BC	105981	2065	10	5.9	3646.7	1.72	100	7	8.4	8.91	759.6	45	5	5
30-Sep-06 08:52	03	643	BC	105981	2014	1	5.8	3646.2	-0.95	67	3	10	9.51	759.7	42	4	4
30-Sep-06 09:52	03	5986	BC	105981	2043	1	6.4	3646.4	1.37	159	1	8.6	9.15	760	39	14	10
30-Sep-06 18:58	03	1155	BC	105981	2249	10	5	3646.2	-0.35	132	1	7.4	23.14	760.5	15	6	6
30-Sep-06 23:04	03	1134	BC	105981	2022	3	5	3644.5	2.06	372	63	8.9	16.08	761.7	28	19	13
30-Sep-06 23:31	03	5986	BC	105981	2022	3	5	3644.5	2.06	38	1	5.7	14.37	762.1	32	10	8
01-Oct-06 01:11	03	1500	BC	105981	2233	16	4.7	3640	2.66	1063	231	21.7	11.35	762.5	39	17	17
01-Oct-06 02:37	03	6179	BC	105981	2015	32	4.4	3641.1	2.11	43	0	19.9	10.51	762.6	36	5	5
01-Oct-06 03:05	03	6178	BC	105981	2015	32	4.4	3641.1	2.11	127	14	22.4	10.7	762.6	32	6	6
01-Oct-06 03:13	03	5557	BC	105981	2015	32	4.4	3641.1	2.11	109	12	6.1	10.55	762.5	31	7	7
01-Oct-06 03:33	03	5986	BC	105981	2015	32	4.4	3641.1	2.11	109	3	6.3	8.9	762.3	36	13	11
02-Oct-06 00:34	03	4378	BC	105981	2131	39	4.6	3638.1	-0.65	192	3	7.3	12.12	761.9	35	27	23
02-Oct-06 01:13	03	8004	BC	105981	2157	60	4.7	3637.3	-1.4	402	22	14.6	11.46	762.2	35	45	34
02-Oct-06 01:31	03	5986	BC	105981	2157	60	4.7	3637.3	-1.4	405	4	7.4	10.85	762.2	36	21	18
02-Oct-06 02:36	03	6178	BC	105981	2455	66	4.8	3636.3	1.11	59	8	8	10.9	762.2	32	11	10
02-Oct-06 05:14	03	8501	BC	105981	2059	43	5.3	3639.4	-1.09	44	1	6.8	8.48	761.1	37	7	6
02-Oct-06 05:28	03	317	BC	105981	2059	43	5.3	3639.4	-1.09	192	15	14.3	8.69	760.8	35	26	12
02-Oct-06 06:53	03	8501	BC	105981	2083	28	5.3	3638.1	-0.4	8	0	10.1	8.2	760.2	34	2	2
02-Oct-06 06:55	03	1134	BC	105981	2083	28	5.3	3638.1	-0.4	168	10	10.7	8.18	760.2	34	10	10
02-Oct-06 07:05	03	1155	BC	105981	2083	28	5.3	3638.1	-0.4	38	0	6	8.29	760.1	36	3	3
02-Oct-06 07:19	03	317	BC	105981	2083	28	5.3	3638.1	-0.4	371	40	9.3	7.7	760.1	34	34	21
02-Oct-06 07:59	03	643	BC	105981	2025	19	5.4	3638.4	0.16	13	0	5.7	7.41	760.1	36	3	3
02-Oct-06 08:48	03	1134	BC	105981	2035	7	5.5	3640.3	0.91	30	3	7.9	7.8	759.9	34	4	4
02-Oct-06 12:57	03	1500	BA	105981	1018	8	6.3	3645.6	0	460	65	16.3	18.1	761.4	18	12	12
03-Oct-06 01:32	03	1500	BB	105981	1007	32	4.8	3636.8	0	182	5	14.8	10.52	761.4	41	4	4
03-Oct-06 02:48	03	5557	BC	105981	2031	139	5.3	3638.3	-0.94	99	6	7.6	10.69	761.7	40	10	8
03-Oct-06 04:45	03	317	BC	105981	1837	27	5.2	3639.4	-1.4	157	6	9.9	9.58	760.6	40	21	18
03-Oct-06 05:32	03	1155	BC	105981	2034	37	5	3638.3	1.67	243	3	8.5	9.13	760.3	41	12	12
03-Oct-06 06:19	03	8501	BC	105981	2039	41	5	3639.6	-0.1	129	15	16.9	9.6	759.8	36	4	4
03-Oct-06 06:40	03	317	BC	105981	2039	41	5	3639.6	-0.1	119	2	8.5	8.85	759.5	36	11	11
03-Oct-06 07:16	03	1134	BC	105981	2017	34	5.3	3640.5	2.09	17	0	6.9	9.2	759.3	32	1	1
04-Oct-06 05:48	03	8501	BC	105981	2031	6	5.1	3644.3	1.81	165	7	7.2	9.8	759.4	33	9	9
04-Oct-06 07:38	03	1134	BC	105981	2040	8	5.1	3643.3	-0.55	272	8	7.9	8.42	758.6	32	7	7
04-Oct-06 07:49	03	317	BC	105981	2040	8	5.1	3643.3	-0.55	26	0	7.1	8.99	758.5	30	7	7
04-Oct-06 07:53	03	1155	BC	105981	2040	8	5.1	3643.3	-0.55	12	0	6.2	8.61	758.6	34	6	5
05-Oct-06 02:11	03	6179	BC	105981	1237	15	5	3643.2	-1.85	249	55	7.9	10.57	760	41	22	20
05-Oct-06 02:29	03	5557	BC	105981	1237	15	5	3643.2	-1.85	23	1	9.7	10.5	760.1	40	2	2
05-Oct-06 02:40	03	6178	BC	105981	1237	15	5	3643.2	-1.85	346	23	8.9	10.61	760.2	39	20	19
05-Oct-06 02:47	03	8002	BC	105981	1237	15	5	3643.2	-1.85	109	6	10.8	10.47	760.2	39	16	11
05-Oct-06 03:54	03	5986	BC	105981	2277	59	5.5	3642.8	1.2	119	1	7	9.88	759.6	39	17	17
05-Oct-06 05:10	03	317	BC	105981	2046	10	5.5	3643.1	1.29	59	3	10.3	9.7	758.9	34	18	8
05-Oct-06 06:12	03	1155	BC	105981	2146	8	5.5	3647.4	0.67	109	0	7.6	9.37	758.3	22	12	4
05-Oct-06 07:04	03	317	BC	105981	2146	8	5.5	3647.4	0.67	306	20	11.1	8.84	758.1	21	19	19
05-Oct-06 07:54	03	1134	BC	105981	2143	8	5.5	3647.9	1.36	405	51	11.1	9.59	757.8	18	11	11
05-Oct-06 08:20	03	643	BC	105981	2143	8	5.5	3647.9	1.36	130	11	6.7	9.38	757.7	17	6	6
05-Oct-06 08:28	03	5986	BC	105981	2143	8	5.5	3647.9	1.36	54	0	7.3	9.31	757.6	17	8	6
05-Oct-06 18:05	03	8501	BC	105981	2060	10	6.7	3655.7	-7.68	47	2	5.9	23.44	758	16	6	6
05-Oct-06 19:22	03	1155	BC	105981	1687	20	5.5	3654.1	1.19	15	1	7.9	23.11	757.5	17	3	2
05-Oct-06 22:41	03	1500	BC	105981	2064	11	5.6	3654.2	1.87	700	91	21.9	18.21	758.7	22	19	19
06-Oct-06 01:53	03	5986	BC	105981	2590	23	5.3	3646	5.19	417	0	8.2	12.35	760.9	33	24	20
06-Oct-06 03:03	03	5557	BC	105981	2174	5	5.4	3649.3	-1.43	33	3	6.1	10.5	761	35	3	3
06-Oct-06 03:19	03	6179	BC	105981	2174	5	5.4	3649.3	-1.43	127	9	7	11.17	761.1	33	9	9
06-Oct-06 06:16	03	317	BC	105981	2063	5	5.6	3650.2	-0.2	450	19	13.1	10.39	759.9	34	27	25
06-Oct-06 06:28	03	1134	BC	105981	2063	5	5.6	3650.2	-0.2	202	41	9.4	10.33	759.9	33	5	5
06-Oct-06 08:14	03	1155	BC	105981	2021	6	5.6	3652.2	0.49	110	0	6.6	10.14	759.2	30	22	15
08-Oct-06 21:59	03	1500	BC	105981	2026	54	4.7	3655.6	0.51	1417	260	17.7	19.89	760.3	24	25	24
08-Oct-06 23:21	03	4378	BC	105981	2192	106	5.2	3653.8	2.72	116	11	7.5	15.79	761	33	20	14
09-Oct-06 04:10	03	317	BC	105981	1527	175	5.7	3649.4	-1.07	11	0	6.5	11.4	761.6	34	2	2
09-Oct-06 04:30	03	1155	BC	105981	1527	175	5.7	3649.4	-1.07	44	5	4.9	11.34	761.4	32	8	7
09-Oct-06 05:37	03	1134	BC	105981	1540	151	5.5	3647.1	-0.87	134	25	6.9	11.5	760.8	29	5	5
09-Oct-06 07:46	03	1155	BC	105981	2063	181	5.4	3647.1	1.83	39	1	10.2	10.03	760	29	6	4
09-Oct-06 08:15	03	643	BC	105981	2063	181	5.4	3647.1	1.83	33	5	6.5	9.1	759.9	25	2	2
09-Oct-06 08:56	03	5986	BC	105981	2044	259	5.4	3647.1	-2.6	272	23	7.1	9.24	760	23	20	14
10-Oct-06 19:01	03	1134	BC	105981	1234	3	6	3660.7	5.77	241	19	7.1	22.35	761.9	20	20	12
10-Oct-06 19:35	03	1155	BC	105981	1234	3	6	3660.7	5.77	60	1	4.9	22.97	761.8	20	5	5
11-Oct-06 09:10	03	5986	BA	105981	1020	1	5.3	3658.7	0	56	0	7.1	12.22	760.9	17	17	6
12-Oct-06 04:42	03	1134	BC	105981	2048	6	5.1	3660	0.29	156	6	5.9	11.84	762.6	29	14	5
12-Oct-06 06:39	03	8501	BC	105981	2023	5	5	3660.5	-0.34	10	0	8.4	11.4	761.5	31	2	2
12-Oct-06 07:11	03	1155	BC	105981	2124	5	4.8	3661.4	-0.14	108	0	6.9	11.57	761.2	30	6	6
12-Oct-06 07:34	03	1155	BC	105981	2124	5	4.8	3661.4	-0.14	32	0	4.9	11.96	761.2	29	6	6
12-Oct-06 08:31	03	643	BC	105981	2092	9	4.5	3659.8	-0.08	96	12	9.5	11.16	761.1	30	4	4
12-Oct-06 10:03	03	1500	BC	105981	2051	8	5	3658.9	-0.77	1083	111	17	11.35	761.6	30	17	17
12-Oct-06 10:56	03	4378	BC	105981	2019	6	5.6	3662.9	2.36	24	0	6	11.6	762	30	6	6
12-Oct-06 17:52	03	1134	BC	105981	1926	17	5	3666.7	-0.02	133	7	7	24.29	761.1	16	14	10
13-Oct-06 08:09	03	643	BB	105981	1041	47	7.3	3654	0	48	3	16.5	9.6	761.1	36	4	2
13-Oct-06 09:39	03	5986	BC	105981	2085	46	6.3	3656.2	-0.8	377	2	7.2	9.03	761.4	36	14	13



Korean Plan for SLR System Development

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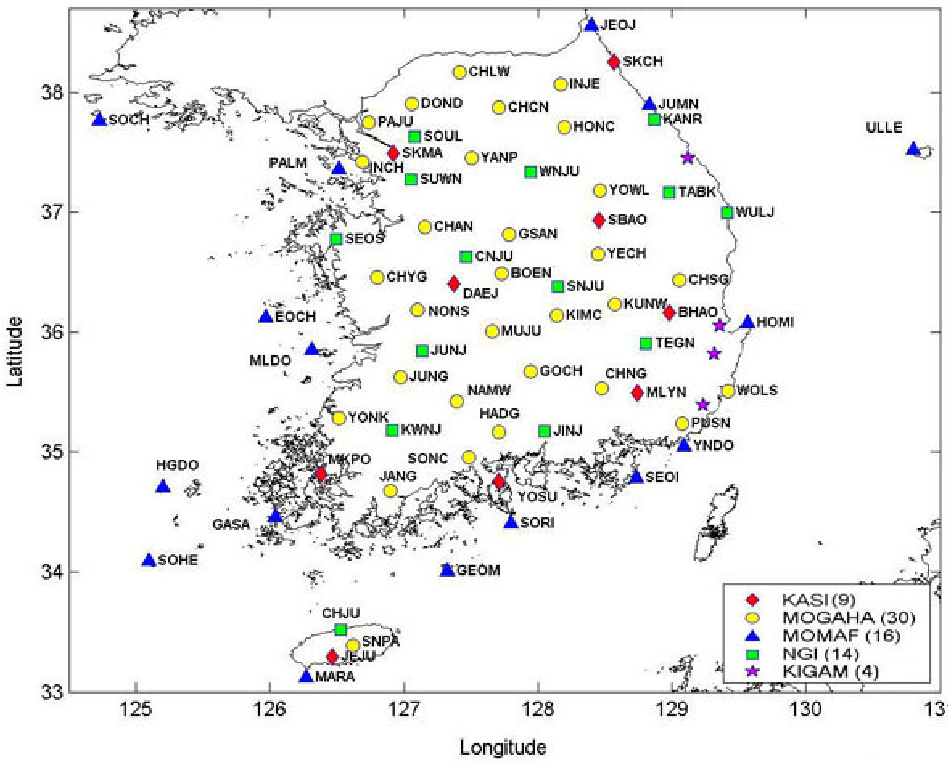
Abstract

There are about 70 GNSS stations in Korea for GNSS applications including space geodesy, and 3 VLBI stations will be constructed by 2007 for astronomical and geodetic research. In addition, two Korean satellites with a laser retro-reflector array, STSAT-2 and KOMPSAT-5, will be launched in 2008 and 2010, respectively. Thus, SLR system is considered to be necessary in Korea for constructed for satellite laser tracking and space geodesy research. KASI has a plan to develop a fixed SLR station and a mobile SLR station in the near future. In this study, future Korean plans of SLR system development will be presented.

Introduction

More than 70 GNSS (Global Navigation Satellite System) stations have been operated by several institutes, including KASI (Korea Astronomy and Space Science Institute), for accomplishing missions of navigation, space geodesy, and so on. From 1995, KASI has been playing an important role in IGS (International GNSS Service) and IERS (International Earth Rotation and Reference Systems Service) as global GNSS station, and operating an IGS global data center from 1996. Except GPS applications, KASI has a wide variety of research areas like optical, radio, theoretical and observational astronomy research, and is expanding its area through astronomical research in space. So, KASI has been constructing 3 VLBI (Very Long Baseline Interferometry) stations with receivers working in the frequencies 2/8, 22 and 43GHz bands which will be completed by 2007 for radio astronomy research including space geodesy. Fundamental stations for geodesy operate three geodetic space techniques at one location: VLBI, GNSS and SLR (Satellite Laser Ranging), which can give a powerful tool for space geodesy such as global reference frame. KASI has a plan of operating a fundamental station in Jeju island in which a GNSS station is already operated and a VLBI station will be completed in 2007. So, KASI wants to develop a SLR system for constructing a fundamental station, and it has tried to raise funds for SLR system development from Korean government.

After KITSAT-1 was launched in 1992, which was the first Korean satellite, Korea launched 6 LEO (Low Earth Orbit) satellites made by Korean technology. They are not all equipped with LRA (Laser Retro-reflector Array) because precise orbit determination is not required in their missions. However, two Korean satellites with LRA will be launched in 2008 and 2010, respectively: Science Technology SATellite-2 (STSAT-2) with a Lyman-alpha imaging solar telescope and Korea Multi-Purpose SATellie-5 (KOMPSAT-5) with a Synthetic Aperture Radar (SAR). STSAT-2 LRA was developed through international collaboration between SaTReC(Satellite Technology Research Center), Korea and Shanghai Astronomical Observatory, China. But KOMPSAT-5 will have the same LRA as Champ, Grace and TerraSAR-X satellites, whose LRA will be made by GFZ (GeoForschungsZentrum Potsdam), Germany.



Korea Astronomy and Space Science Institute (KASI)
Ministry of Government Administration and Home Affairs (MOGAHA)
Ministry of Maritime Affairs and Fisheries (MOMAF)
National Geographic Information Institute (NGII)
Korea Institute of Geoscience and Mineral Resources (KIGAM)

Figure 1. *Korean GNSS Network*

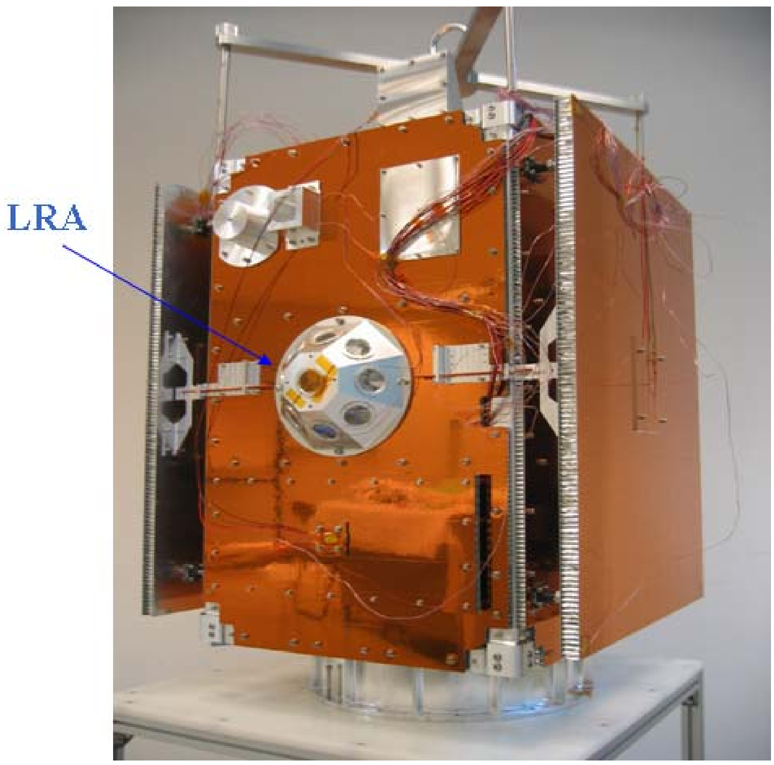


Figure 2. *STSAT-2(first Korean satellite with LRA)*

Future Plan for SLR system development

KASI conducted the preliminary study for SLR system development from December 2004 to November 2005 with KAERI (Korea Atomic Energy Research Institute), KIMM (Korea Institute of Machinery and Materials) and SaTReC (Satellite Technology Research Center). In the preliminary study, KASI carried out a feasibility study on SLR system development and made the conceptual design of Tx/Rx telescope and Control & Operating System. The conceptual design of the laser generator was done by KAERI, the tracking mount by KIMM, and the Tx/Rx electric system by SaTReC. KASI has tried to obtain the financial support of the Korean government for SLR system development (KSLR project) since this preliminary study, and wants to start the KSLR project in 2008 with KAERI, KIMM and SaTReC. In this project, one fixed system with a 1m Rx telescope and one mobile system with 40cm Rx telescope will be developed for 5 years. The detailed requirements of a fixed system are shown in Table 1. The mobile system will be integrated by introducing the core subsystems from abroad, and the fixed system will be developed through the international and domestic collaboration. So, it will take about 3 years to develop a mobile system but 5 years (subsystem development: 3.5yr, system integration: 0.5yr, test operation: 1yr) to develop a fixed system. After a fixed SLR system is constructed, KASI will join to ILRS (International Laser Ranging Service) for the contribution of the international SLR society.

As mentioned in the previous section, STSAT-2 will be launched in 2008 when Korea will not be capable of tracking it. So a mobile system (TROS, Transportable Ranging Observation System) will be introduced in China this June for laser tracking of STSAT-2 but the detailed schedule is not fixed

Table 1. *Requirements of the future Korean SLR system*

Items	Requirements
Tracking Coverage	• Possible to track satellites in the altitude of 25,000km • STSAT-2, KOMPSAT-5, GPS, Galileo Satellites and so on.
Ranging Accuracy	• Lageos : 10mm(SS), 1-2mm(NP) • GPS and Galileo : 20mm(SS), 3-5mm(NP) • Ground Target : 3mm(SS), 1mm(NP)
Automatic Operation	• Remote control from the remote site via internet or dedicated line. • Aircraft detection using radar and automatic observation according to the schedule.
Etc	• Daylight tracking. • Optical tracking of the space launch vehicle (if possible).

Summary

Two Korean satellites with LRA, STSAT-2 and KOMPSAT-5 will be launched in 2007 and 2009, respectively. Therefore, SLR system is steadily required to be established in Korea not only for satellite tracking, but also for space geodesy research by using GNSS and VLBI. In response to this demand, KASI have prepared for development of SLR system for several years, and expect to launch the project for the development of SLR system from 2008. KASI has a plan to develop one mobile and one fixed SLR systems for 5 years. After a fixed SLR system is constructed, KASI will join ILRS and participate in the international tracking campaign.

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Study on Servo-Control System of Astronomical Telescopes

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Abstract

Based on recent and modern control theories, this paper describes an analysis of the control system compensation function and its application to astronomical telescope servo control requirements. It discusses corresponding compensation networks for modern astronomical telescopes.

Keywords: *Servo System, Compensation Network, SLR/LLR telescope*

Introduction

Most of modern telescopes servo-control systems are computer closed loop control systems which are based on classical control theories and are composed of one or more feedback control loop. Typical feedback control system is shown in Fig.1. In theory, control system designed according to this block diagram might meet the requirements. However, in a concrete project, control system simply designed like this way is not simultaneously satisfied with all the requirements until it is compensated properly.

C(s) represents controlled output, its value is sent back through feedback controller

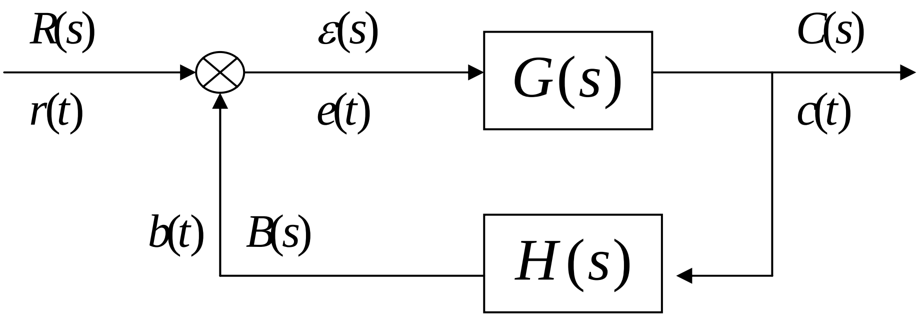

Fig.1 *Typical Feedback Control Loop*

whose transfer function is H(s). Its output B(s) is compared with expected output R(s), i.e. input of whole control system, the error which R(s) substracts B(s) is sent into controller G(s), which adjusts the error to near zero.

Compensation of Control System

In order to carry out expected capability, modifying and adjusting the control system structure is named compensation. In another words, compensation is used to adjust structure for compensating defect of system. PD (Proportion Differential) Compensation Network and PI (Proportion Integral) are often used in modern control system design. Corresponding control loop block diagram is shown as Fig.2. Gc(s) is the transfer function of the compensation network. [1]

PD Compensation Network Function

When compensation network transfer function $G_c(s)$ is:

$$G_c(s) \approx \frac{k}{p} s$$

it is a PD type compensation Network.[2] Fig.3 is its corresponding bode graph, which is magnitude versus phase plot. It could be clearly seen that magnitude gain increases with frequency and phase is greater than zero. This means that PD compensation can offer additional phase for primary system without compensation network.

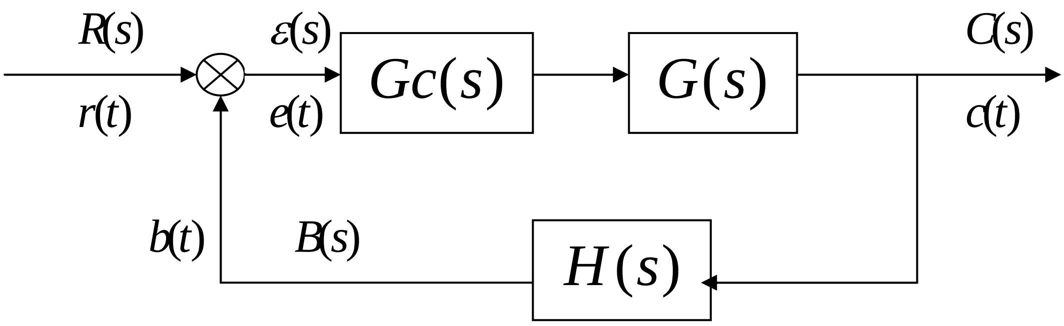

Fig.2 *Feedback Control Loop with Compensation*

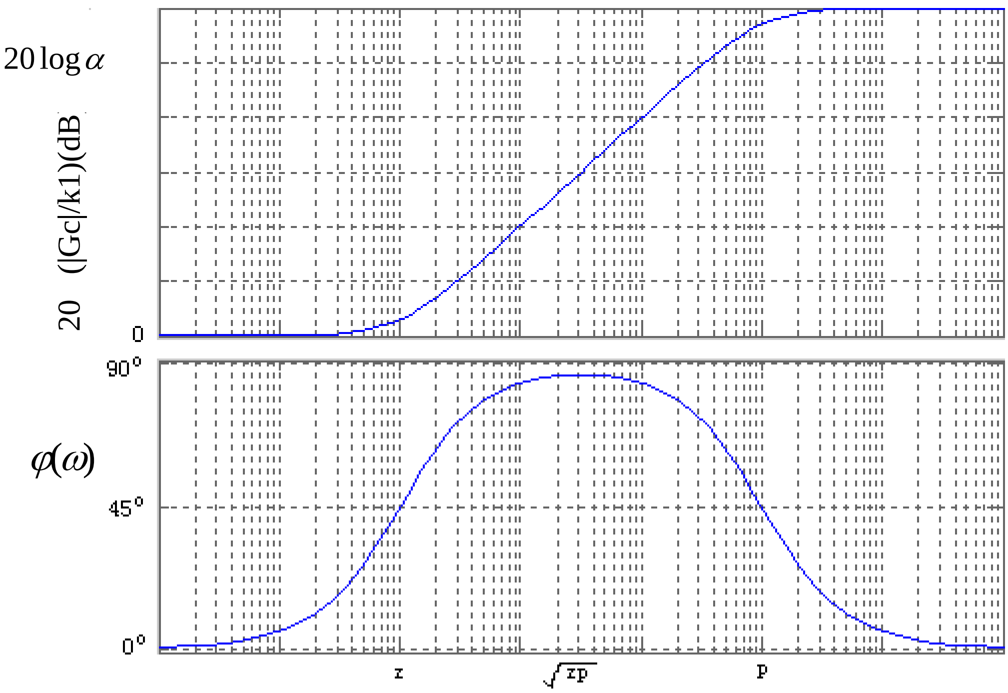

Fig.3 *The Bode Graph of PD Compensation*

Therefore, to make system response more quickly and strengthen system stability is the function of PD compensation.

PI Compensation Network Function

When compensation network transfer function $G_c(s)$ is :

$$G_c(s) \approx \frac{k}{ps}$$

it is a PI type compensation Network.[2] Fig.4 is its corresponding bode graph, which is magnitude versus phase plot. It is obvious that magnitude gain descends with frequency and phase is negative. This shows that PI compensation can offer delay phase for primary system without compensation network. So, the function of PI compensation is to improve system accuracy of stability. To sum up, PD compensation may be used to improve instantaneous response and PI can be used to meliorate stable response.

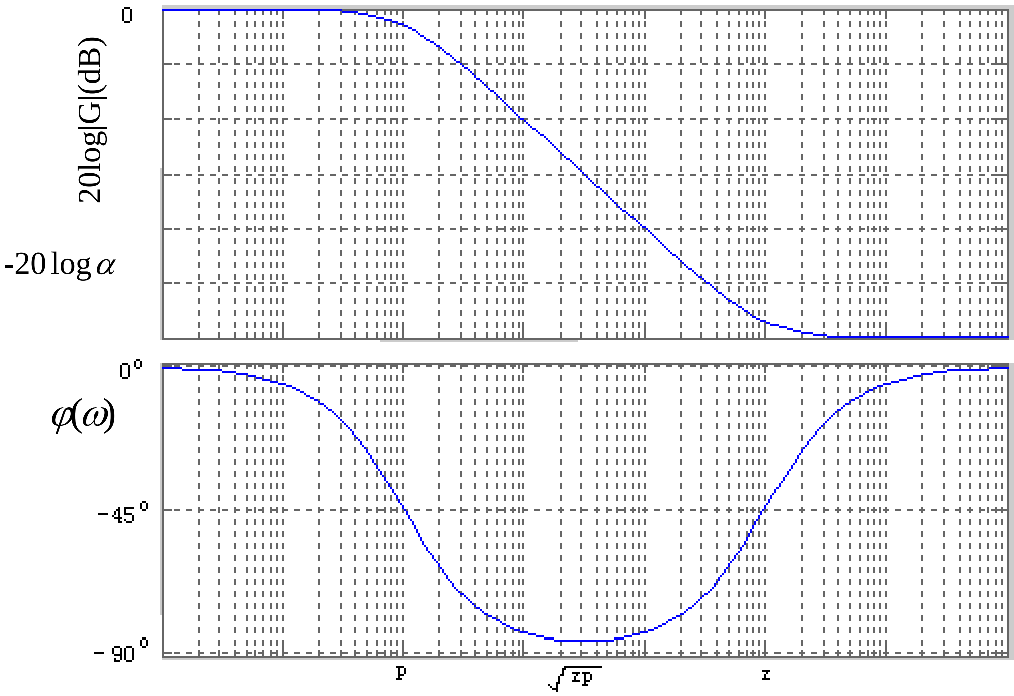

Fig.4 *The Bode Graph of PI Compensation*

Compensation Network Design for Telescope Servo System

According to characters of the compensation network which were analysed above, we could design a proper servo control system for any astronomical telescope.

If a telescope is required to track quick motion celestial bodies, such as satellites near the Earth, we would design the control system compensation network as PD compensation, or PI compensation would be better to observe slow motion celestial bodies for a telescope.

Of course, when a telescope is not require to track quick motion celestial bodies but slow motion bodies, to combine advantages of PI and PD could gain the expected performance or we could directly design the control system compensation network as PID compensation.

Discussion

Though PID compensation network could attain better capability, its disadvantage is that needs more devices and increases design cost. Therefore, if a telescope need track both quick and slow bodies, in order to save resource, we'd better select PD compensation network, then through software methods to compensate the accuracy of stability.

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Russian Laser Tracking Network

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Abstract

Basic parameter are presented of six laser tracking stations now installed in Russia. Besides SLR, the stations also provide angular measurement and photometry.
Some applications of obtained data are also specified.

Introduction

The Russian SLR stations comprise three optical channels: ranging channel, angular measurement channel, and photometric channel, providing the following accuracy of measurements:

- Ranging: 5 - 10 mm (RMS of NP)
- Angular measurements (in reflected sunlight): 1 arcsec

Photometry (in reflected sunlight): ≈0.2 star magnitude.

Ranging data applications

The high precision of laser ranging allows use of SLR as a single source of calibration data for GLONASS ephemeris determination, providing solution of following problems:

- Estimation of accuracy, and calibration of radio-frequency means for GLONASS orbit measurements.

- Providing SLR stations with geodetic-class RF navigation receivers connected to hydrogen maser frequency standards allows monitoring of on-board clocks and use of the data for operational control of GLONASS time and ephemeris data.

- SLR station coordinates are used as geodetic base for the GLONASS reference frame.

- SLR data are used to provide declared values of ephemeris precision, as well as to provide computation and forwarding of accuracy factor in the navigation frame of GLONASS – M spacecraft.

Angular measurement data applications

Angular measurement data obtained on SLR stations are used for implementation of single-point scheme of flight control for commercial geostationary spacecraft with periodical measurements of orbit inclination to provide retaining of the geostationary spacecraft standpoint within ±0.1 deg. in longitude and ±0.1 deg. in latitude.

Photometric data applications

- The presence of a high-sensitivity TV channel provides registration of flight phases (motors turn-on, booster separation, etc.) during launching of spacecraft on high elliptical and geostationary orbits.

- The photometric channel supports determination of spacecraft motion relative to its center-of-mass, as well as of its attitude stability.

Taking into account the unfavorable astro-climatic conditions on most of the country territory, efforts are made to expand the Russian laser tracking network. Currently, five SLR stations are in operation. In 5 years, the number of stations will increase to 15…20, as declared in the new Global Navigation System Federal program.

Russian laser tracking network

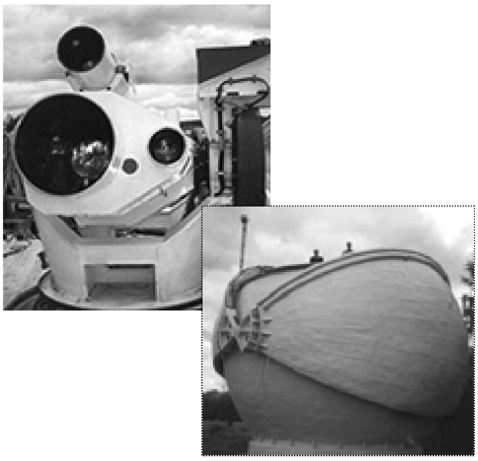

Figure 1: *SLR Station in Shelkovo (near Moscow)*

Figure 2:*Altay Optical and Laser Tracking Center*

Figure 3:*Komsomolsk SLR station*

Figure 4: *Compact SLR station installed in Arkhys (North Cuacasus)*

Figure 5: *Maidanak Optical and Laser stations (Uzbekistan) (currently, an inter-state agreement is under preparation concerning the mutual control and operation of this station).*

Figure 6: *Mobile SLR station installed in Baikonur*

Figure 7: *Russian laser tracking network*

TLRS-4 Deployment to Maui, Hawaii

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Abstract

With the completion of the TLRS-4 Operational Readiness Review in the fall of 2005, Honeywell Technology Solutions Inc (HTSI) working with the University of Hawaii Institute for Astronomy (IfA), deployed the NASA TLRS-4 system to the 10,000 foot summit of the Haleakala volcano on September 7th, 2006. TLRS-4 is returning a critical data point to the ILRS Global solution following the closure of the HOLLAS SLR station in 2004. This paper describes the planning, deployment, current status and future at the Haleakala Observatory.

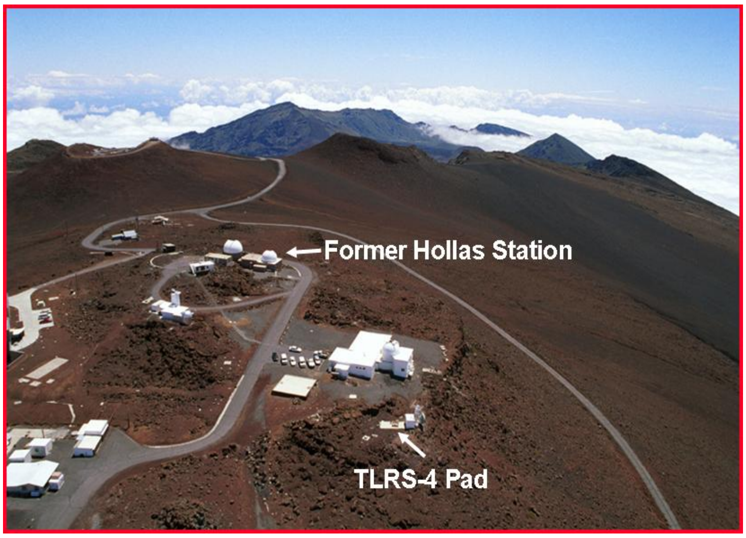
Background

The NASA Transportable Laser Ranging System (TLRS) number 4, TLRS-4, was returned to operations during spring and summer of 2005, following approximately 10 years of inactivity as an operational station in the NASA SLR Network. A highly

successful inter-comparison test with Moblas 7 validated that TLRS-4 was ready for deployment. Following the Operational Readiness Review on September 15, 2005, TLRS-4 was readied for deployment to the 10,000 ft summit of the Haleakala volcano on Maui, Hawaii. The system was to be operated by the University of Hawaii (UH), Institute for Astronomy (IfA) under contract to NASA, returning a critical data point in the Pacific Ocean. As the Hollas system had been decommissioned in 2004 following budget reductions at NASA, the site was converted to the new PanStarrs Observatory. To return SLR to the Haleakala Observatory, the TLRS-4 system was provided and would be moved to a pad within approximately 100 meters of the Hollas station. The figure below shows the location of the former Hollas system and the location of where TLRS-4 system would be deployed.

Haleakala Observatory Site Preparations

As the Hollas site was no longer available for SLR, a suitable location for TLRS-4 was required. One was found near the Mees Solar Observatory, however there was inadequate infrastructure to support SLR operations. Improved infrastructure to be considered included: pad, power, grounding voice and data communications, calibrations piers, site safety and site and system survey. Even though the IfA had no formal contract in place with NASA, they provided excellent coordination for all efforts of site preparations that would be required to locate TLRS-4 at the observatory.



During this period when no contract existed with the IfA, the system remained in a semi-operational mode at the Goddard Geophysical and Astronomical Observatory (GGAO) in Greenbelt, Maryland at NASA SLR Headquarters.

Also, during this time, a dome safety retrofit project occurred in Maryland to provide a remotely operated and weather hardened dome and shutter to meet with the sometimes harsh wind and rain conditions at the summit of the Haleakala volcano. Additionally, an upgrade to provide for 4 Hz tracking for high orbital satellites occurred and the TLRS systems were not originally designed to high satellite tracking.

In April 2006, in anticipation of the IfA, NASA contract being finalized and due to the time required to transport the system from Maryland to Hawaii, it was determined to ship the system to Maui. The system arrived in Maui in late May 2006. As the contract had not been finalized, the shipment consisting of the Ranging Van, the Support Trailer and the radar platform and tracking dome, were placed at the Waiakoa, IfA office property located at 3,000 feet for holding until the system could be sent to the summit. A key milestone to be completed once the contract was in place was a site occupancy permit and permit to perform infrastructure modifications at the observatory.

When the contract was approved in late spring a occupation and building permit was applied for by the IfA. The permit was received in mid-August 2006 and site preparations were begun.

The Haleakala volcano is rich in native Hawaiian history, culture and religion. A cultural observer was required to approve and oversee all work performed on the site

where any disturbance may occur to native soils. Special requirements and permissions for excavation, removal and replacement of ground were followed and it was required that any person working on the project to be provided with a training and a cultural introduction to the religious and historical significance and understanding of working in Hawaii.

Following this training and receipt of the permitting, both HTSI and IfA worked aggressively to ready the site for occupation of the TLRS-4 system. Major components of site infrastructure included the calibration piers and site power. The previous figures show the unoccupied pad and the construction of the calibration piers. Temporary site power was provided from the Mees Observatory.

On September 6, 2006, the TLRS-4 was readied for transport from the IfA offices in Waiakoa to the summit. The newly fabricated dome and radar platform were installed at the Waiakoa office prior to loading the tracking van on the flatbed for the trip to the summit.

The Operations Van and the Support Trailer were delivered and installed on a rainy September 7th and placed on the pad shown above. Since that time, connection to the temporary site power, setup of the two vans and the reenergizing of the system began with the IfA and HTSI team.

An interesting point of working at the Haleakala Observatory is that the crew is required to drive from either sea level or near sea level to the 10,000 foot summit daily. Working conditions with such a daily change in altitude affect how the workers exert effort both mentally and physically. As one never completely adapts to the high altitude, greater concentration in routine physical and mental tasks, are required.

Transition of the TLRS-4 from the HTSI team to the IfA was seamless due to the extensive background in SLR that was retained by the University of Hawaii with key people such as Dan O'Gara and Jake Kamibayashi, the close similarities between the TLRS-4 software architecture and the Hollas system. More significantly, the new TLRS-4 Station Manager, Craig Foreman, spent months in Maryland in the restart effort of the TLRS-4 system and was responsible for many of the modifications of the system to operate in the Haleakala summit environment. Craig's success was ensured by working with the HTSI team especially Maceo Blount who lead the installation team to Maui for the installation and training of the other IfA personal.

Current Status

At the time of this report, the TLRS-4 station setup is completed. During the startup of the system, there was a laser failure that was being troubleshot. Also, during this time, optical alignments were being completed and the other components and subsystems were being verified. Site power to the system was being used on a temporary basis from the Mees Observatory while a permanent source was being developed.

Remaining efforts and future plans for TLRS-4 include completing the System Operational Verification Tests (SOVT), ground calibration testing, satellite tracking and validation of data acquired. Also required actions include completing the site survey analysis and report generation, updating of the Site Log, and completion of the training aspect of TLRS-4 to the IfA crew.

Power switchover to a more permanent solution will require further effort, approval by the cultural observer and contracting with local contractors and the local power company. During this period, the ground field will be enhanced to reduce ground currents on station. Locating an SLR station located at the top of a dormant volcano produce unique grounding opportunities that must be resolved in unique ways.

Conclusion

In conclusion, acknowledgements of the many extra efforts and the dedicated team that worked to reach a successful conclusion to the project that restores an important piece of the global puzzle for the reference frame and for SLR go to NASA with the leadership provided by David Carter. Also to the HTSI Team led by Howard Donovan and his the team of professionals including Don Patterson, Dennis McCollums, Tony Mann, Michael Heinick, Julie Horvath, Bart Clarke, Oscar Brogdon, Maceo Blount, and Craig Foreman. And finally, the team from the University of Hawaii, Institute for Astronomy and the extra efforts provided by Dan O’Gara, Mike Maberry, Jeff Kuhn, Jake Kamibayashi and Les Hieda.

New SLR Station Running in San Juan of Argentina

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Abstract

The new SLR station in San Juan of Argentina is the result of a kind of cooperation of science and technology between China and Argentina and it was running by the twenty second of February of 2006. The whole SLR system in the station was designed and developed by Chinese Academy of Surveying and Mapping (CASM) and National Astronomical Observatories (NAO) of Chinese Academy of Sciences in the years of 2000 to 2003. The investor for the SLR system is the Ministry of Science and Technology of China. The new station building including the dome in the field of Observatorio Astronomico Felix Aguilar(FELIX), Astronomical Observatories of San Juan National University of Argentina, was designed and constructed by San Juan National University of Argentina. The approximate site position of the station is 31°30´31".050S, 68°37´23".377W and the height is 727.22m. The new SLR facility in San Juan station features a good accurate and prolific SLR system according to the data reports of ILRS data analysis centers. The current status, the future update and some questions for the SLR system in San Juan station are also mentioned in this paper

Background

The new SLR system in San Juan of Argentina is based on the Science and Technology cooperation between National Astronomical Observatories (NAO), Chinese Academy of Sciences and San Juan National University of Argentina. The supporter and investor for the project are the Ministries of Science and Technology of the two countries. In fact, for more than 10 years the Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) and National Astronomical Observatories (NAO), Chinese Academy of Sciences have developed friendly cooperation on astronomical research and observation. Under the efforts of the both Observatories the cooperation on cataloguing the Southern Parts of the Earth and astronomy geodynamics using the photoelectric astrolabe MARK II (PA II) has been successful and got lot of interesting results.

At November of 2000, National Astronomical Observatories (NAO), Chinese Academy of Sciences and Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) subscribed a cooperation agreement on satellite laser ranging (SLR) to extend the relationship between the two observatories for astronomical observation and research. It is very beneficial to set up a new fixed SLR station in Argentina of South America, which located in the southern parts of the Earth, as the distribution of the SLR stations in the world will be improved better.

According to the agreements of the cooperation the Chinese Academy of Surveying and Mapping (CASM) is responsible for design, developing, installing and debugging of whole SLR system and technical training to the persons from National Astronomical Observatories (NAO) of Chinese Academy of Science and Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA).The National

Astronomical Observatories (NAO) of Chinese Academy of Science is in charge of packaging of whole SLR system and to ship it to Argentina. And San Juan National University of Argentina with its Felix Aguilar Astronomical Observatory takes charge for whole constructions and decorations of the SLR room including the mobile roof of the building.

The whole SLR system was designed and developed by Chinese Academy of Surveying and Mapping (CASM) and National Astronomical Observatories (NAO) of Chinese Academy of Science in the years of 2000 to 2003 and checked and accepted by China Ministries of Science and Technology at 12th of January, 2004. The main body of the new station building in Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) was completed in August of 2005 by San Juan National University of Argentina.

So there are three layers for the scientific and technical cooperation between China and Argentina. The first and top layer, the government layer, is between the two Scientific and Technical Ministries of the two countries and this is on the layer of policy. The second layer is between National Astronomical Observatories (NAO) of Chinese Academy of Sciences and San Juan National University of Argentina and this is on the layer of administration. The third layer is between Chinese Academy of Surveying and Mapping (CASM) and National Astronomical Observatories (NAO) of Chinese Academy of Science and this is on the layer of putting in practice.

Figure 1: *San Juan SLR Station*

Figure 2: *SLR Telescope*

Site Installation

The San Juan SLR station is located in the site of Felix Aguilar Astronomical Observatory in San Juan. San Juan city is 1300km Northwest from Buenos Aires the Capital of Argentina and it is the capital city of San Juan province. San Juan is No.12 of biggest city in Argentina with its population of 20,000 citizens in downtown area. The weather in San Juan region can go up to 50º in summer with very dry character of desert Climate and it is not cold in winter time with the lowest temperature of 5º. There are plenty of fruits and melons in harvest seasons especially the grape. So San Juan is very famous for its good quality and high productivity of the wine.

Felix Aguilar Astronomical Observatory has two observation stations, the Felix Aguilar station and Leonato station. The Felix Aguilar station is about 10 km from the city center of San Juan and the office building of the Observatory is there as well as the

SLR station. The Leonato station near Andes Mountains is 200 km from San Juan city and some astronomical instruments from Germany, America and Spain in use for science and technology cooperation.

So the San Juan SLR station not far from the city San Juan and with 300 good days for SLR observations is a excellent site for astronomical observations. The geographic positions of the site are 31°30´31".050S, 68°37´23".377W and 727.22m. There is an another astronomical device in use for nearly 10 years long the photoelectric astrolabe MARK II (PA II) also cooperated with National Astronomical Observatories of China. The groundwork for the SLR telescope is not good with its screen and sand underground and no base stones within 100 meters in deep.

Installation Time Table

The whole set of the SLR device reached San Juan of Argentina on 6th of Aug., 2005. Then we were waiting for the inspecting from Argentina customs for a month and opened the cargo container on 24th of Sep. From this date to about 20th of Nov., 2005 we were waiting for the decoration of the SLR buildings and for modifying the base pillar of the telescope and the bottom of the laser. On 28th of Nov., 2005 the installing started and the installing ended on 23rd of Feb., 2006 with the first Lageos pass of data returns received last night of the date before. That means we got the first SLR pass of satellites data in San Juan Station on the night of twenty second of Feb., 2006 and sent the data to ILRS and running the station on 23rd of Feb., 2006.

Installation Difficulties

The first difficulty is insufficient for the space of installing. For safety of the transportation from China to Argentina we packaged the whole SLR systems separately to the minimum units. And we needed the base pillar of the telescope and the whole second floor under the dome that must be strong enough and stable enough to the work to do the main mirror and second mirror installing and debugging. But the base pillar still needed to repair and the second floor under the dome was made of thin wood board

***Figure 3**: Installing and debugging*

so the mirrors installing and debugging have to be in a big storage. It was not easy to do such a kind of working in a storage so it takes our nearly a month.

The second thing is the Base pillar of the telescope not fit with the telescope in height and orientation. So we have to change the height of concrete base pillar and some holes in positions and sizes. And that is very hard to do. Base for laser platform is too high and we spend lot of energy to cut the base by electric drilling machine.

Figure 4: *Base of laser platform and Base pillar of the telescope modifying*

Decoration for whole laser building not finished. So we have to do the installing and debugging for the SLR system and the decorating for the SLR building at same time. The mobile roof of the telescope we call it "dome" moves unreasonable. That repeatedly made problems with us and not safe as well.

Installation Personnel

Professor T. Wang from Chinese Academy of Surveying and Mapping (CASM) is responsible for whole installing and debugging and in charge of optics and telescope star calibrations. Professor T. Guo from Institute of Seismology, China Earthquake Administrations is responsible for electronics design and installing. Senior engineer W. Liu from National Astronomical Observatories of China is responsible for electronics and laser installing, debugging and daily maintain. Senior engineer D. Huang also from National Astronomical Observatories of China is responsible for installing and daily observations. Engineer Q. Xiang from Chinese Academy of Surveying and Mapping (CASM) is responsible for installing and daily observations. Senior engineer A. Gonzalez from Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) is responsible for electronics installing and The daily observation and maintains. Senior engineer R. Podesta from Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) is responsible for daily observations and maintains. Senior engineer E. L. Actis from Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) is responsible for daily observations and maintains. Senior engineer E. Alonso from Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) is responsible for daily observations and maintains. Senior engineer

***Figure 5**: The San Juan SLR Station Team*

A. M. Pacheco from Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) is responsible for daily observations and maintains.

Daily Observations and Maintenance

To Argentina side: Monday through Wednesday 4 persons are shift on duty for observations but every day a Chinese people must be present at beginning.
To China side: Thursday to Sunday 3 persons are shift on duty and every day the free person in china side is in charge of cleaning, cooking and shopping for their living. So the work is heavy for every one.

Hope:

We hope getting 6000 passes of satellite data from all SLR satellites a year including 1200 passes from satellites Lageos-1 and Lageos-2 each year. And we hope the all data we get will have good quality.

***Figure 6:** Daily Observations and review*

Problems and Questions:

The San Juan SLR station can get 6000 passes of satellite data from all laser satellites per year and they are all night productivities. That means the SLR system in San Juan station has no daytime ability now. This question refers to the laser system itself and we need a stable laser to finish the daytime ability to the SLR system.

In San Juan station the Laser is not only unstable and the spare parts damaged badly. Maybe in the laser system there are some designs unreasonable and we need to adjust the laser system every 3 or 4 days. We have only 3 sets of spare mirrors for the laser and short time after they are all damaged. So recently we have to change the positions of the damaged mirrors maintaining the laser beam output with very unstable some times. This is the second problem in San Juan station.

Some times different persons produce different quality for the data due to laser instability. Not every person can be in control of the laser adjusting so different data quality was produced in the people's shift of on duty from time to time. Dome moves difficulty and not safety are the problems and questions also. At beginning the data have big range bias due to the damaged chip in timing circuit board and now it is ok by change the chip. Running is more difficult compare to in China due to the delay of time for the spare parts transportation from China to Argentina.

Future Plan

The National Astronomical Observatories (NAO) of Chinese Academy of Sciences and Felix Aguilar Astronomical Observatory of San Juan National University of Argentina (OAFA) and Chinese Academy of Surveying and Mapping (CASM) will continue cooperate to the updating of SLR system in San Juan in the near future. The upgrading in first step is to change the SLR system to a new generation system that means we will have KHz and daytime ranging ability of course the semiconductor pumped laser as well.

But it is not soon due to the three layers cooperation and time is needed for finance support from the government and also the performance and the development of the new system need lot of time to do lot of things from China to Argentina.

The Instrumentation

The System Profiles:

The telescope was mostly rebuilt in a storage in San Juan station. It consisted of a Cassegrain receiving telescope of 60 cm aperture and a separated Galilei Telescope which collimated the laser beam with a factor of about 4.

The control computer is a common PC, even a notebook can be also, under windows operating system. All programs like satellite predictions, tracking the targets, ranging the data, data preprocessing and send the data to ILRS etc. are running on the same machine. The control computer is connected to the control interface box by parallel line and the servo system accessed to the control interface box by serial communications.

- Laser system is a Nd:YAG passive mod-locked dye laser with 30ps pulse width and single pulse energy of 30mj in green light.
- The detector is Compensated Single Photon Avalanche Diode (C-SPAD) from Czech Technical University.
- Stanford Counter SR-620

- TV system is Image Intensifier plus CCD and it collect the star and laser beam image by the main receiving telescope.
- Timing and frequency is by HP58503A GPS time and frequency receiver.
- Calibration short distance target, out-install, inside the dome.

The frame diagram of profiles for the whole system is shown as following diagram.

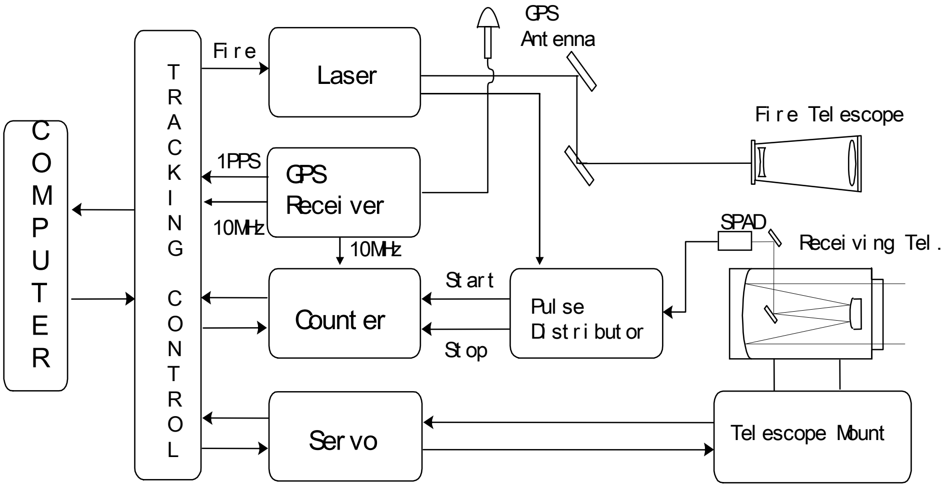

Figure 7: The frame diagram of profiles for the system

Figure 8: Control Room for SLR

Figure 9: The Laser System

Figure 10: The short distance Ground Target

Figure 11: Monitoring Screen

Optical System:

The optical receiving system has a microcrystalline glass main mirror (weight 80kg) with the diameter of 630mm and a microcrystalline glass secondary mirror with the diameter of 200mm. Also there are a spectroscope, an adjustable set of pinhole, an autocollimator and a broadband filter of 10nm in the optical receiving system. The optical receiving system is able to receive both visible light for ICCD and green laser for ranging detector without any additional adjustment due to the spectroscope.

For the transmitting path the laser beam can be guided to the Coude path via 2 reflecting mirrors and a beam expander of 2 times from the laser platform. The Coude path has 6 reflecting mirrors and from the Coude path the laser beam is guided to 16 cm diameter transmitting telescope and to the satellites.

The optical receiving and transmitting path can be shown as following drawing:

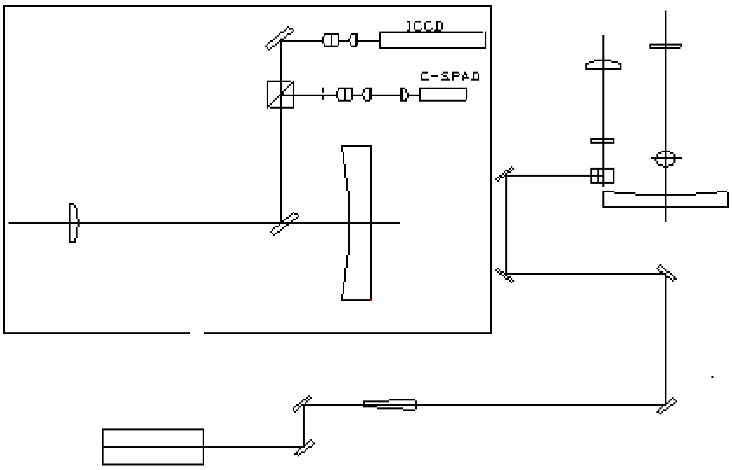

Figure 12: *Optical TR path.*

Laser System:

The computer controlled passive mode-locked laser (Nd: YAG) firing rate up to 10Hz has the pulse width of 30ps and pulse energy of 30mj for wavelength 532nm laser. It is produced by Shanghai Optics and Electronics Institute. The principle diagram of the laser is shown as following diagram:

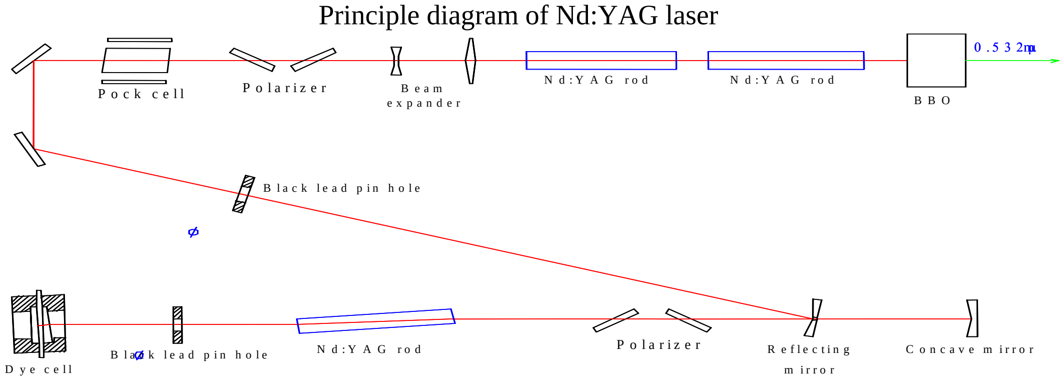

Figure 13: *Laser System.*

Tracking Control and Servo:

A common PC computer is used for telescope control, range gate setting, laser firing and data acquisition etc. All software including satellite predictions and data pretreatment is running in windows operation system and all things can be done just by the computer mouse.

Summaries

The New SLR station in San Juan of Argentina has being running since 23rd of Feb. 2006 and up to 30th of Sep. 2006 nearly 4000 passes of SLR data were sent to the analysis centers of ILRS including 799 Lageos passes and 509 high satellite passes in about 7 months (220 days) from the 2006 3rd quarter report of SLR Global Performance Report Card. That means the San Juan station has the possibility to get 6450 passes for all SLR satellites including 1325 Lageos passes and 844 high satellite passes.

Especially for the Galileo satellite GIOVE-A the San Juan station got 36 passes and it is the number 2 in the quantity line of GIOVE-A satellite by stations only following the station 7090 Yarragadee in Australia which got 45 passes.

The data quality is also very good with the calibration, satellite and Lageos precisions (RMS) of 12.4, 11.0 and 13.3 mm also from from the 2006 3rd quarter report of SLR Global Performance Report Card.

The fact above can prove the cooperation of science and technology between China and Argentina in the field of Satellite Laser Ranging is excellent successful. The SLR system in San Juan station developed by the scientists of China and Argentina has fine capability and stability although the laser is not stable and needs lot of work to maintain. The weather in San Juan station is very good we can say and be reassurance about it.

There are lots of acknowledgments to Professor Guo Tangyong from Institute of Seismology of China Earthquake Administrations and the people from Shanghai SLR station and other stations in China Laser Tracking Network for their efforts in the project.

System Improvement and GIOVE-A Observation of Changchun SLR

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Abstract

This paper introduces the system improvement for tracking GIOVE-A in Changchun station. During the more than two months improvement, the new servo and encoder systems were installed. And primary mirror, second mirror and some other mirrors have been cleaned and recoated. The laser system was adjusted in order to improve the laser efficiency and output. The paper gives out the improvement results, and the GIOVE-A satellite observation results.

Key Words: *system improvement, GIOVE-A observation, SLR*

Introduction of project background

Galileo system consists of 27 satellites distributed in three uniformly separated planes. In 2006, two GSTB-V2 satellites were planned in orbit. The nominal lifetime is 2 years. Four IOV Galileo satellites were planed to be launched towards the end of 2007. Full Deployment Phase and Long Term Operation will be followed the IOV. Galileo In-Orbit Validation Element (GIOVE) satellites: GIOVE-A and GIOVE-B. The objectives of the deployment of these two satellites are to:

- secure use of the frequencies allocated by the International Telecommunication Union (ITU) for the Galileo system
- verify the most critical technologies of the operational Galileo system, such as the on-board atomic clocks and the navigation signal generators
- characterize the novel features of the Galileo signal design, including the verification of user receivers and their resistance to interference and multipath, and
- characterize the radiation environment of the medium-Earth orbit (MEO) planned for the Galileo constellation.

GIOVE-A and -B were built in parallel to provide in-orbit redundancy and to secure the mission objectives. They provide complementary capabilities. GIOVE-A was launched on December 28, 2005, into an MEO with an altitude of 23,260 kilometers. Carrying a payload of rubidium clocks, signal-generation units, and a phase-array antenna of individual L-band elements, GIOVE-A started broadcasting on January 28, 2006, securing the frequencies allocated by the ITU for Galileo. Performance of the on-board atomic clocks, antenna infrastructure, and signal properties is evaluated through precise orbit determination, supported by Satellite Laser Ranging (SLR), an independent high-precision range measurement technique for orbit determination based on a global network of stations that measure the round-trip flight-time of ultra short laser pulses to satellites equipped with laser retro reflector arrays (LRAs). SLR provides instantaneous range measurements of millimeter-level precision which can be compiled to provide accurate orbits and to measure the on-board clock error.

Fig.1. *Changchun SLR telescope*

Due to the urgent need, it is necessary to select an existing SLR station to provide laser ranging service for GSTB-V2 satellites. Given the importance of SLR data for the characterization of the GIOVE clocks, the People's Republic of China contributed to the Galileo program the refurbishing of a Chinese SLR station to provide GIOVE laser-ranging observations. The Changchun station in northeast China was selected among the Chinese stations contributing to the ILRS because it had demonstrated strong MEO satellite tracking; collocation with an existing International GPS Service station; and good weather conditions. There are 5 fixed SLR stations in China nowadays. Among the stations, Changchun station possesses the best performance. Its data quantity is the most in China. It has the ability to range to the distance more than 20,000km with the accuracy less than 2cm. So Changchun SLR Station is selected to service for Galileo in the early stage. Followings are photos of Changchun station and SLR telescope:

Fig.2. *Bird view of Changchun station*

Changchun Observatory (ChO) of National Astronomical Observatory, Chinese Academy of Sciences, is a member of global SLR and GPS networks. It started Satellite Laser Ranging (SLR) since the early of 80th last century. The third generation of SLR in ChO was established during 1985. The system has the ability of tracking satellites with the distance of more than 20000km. Single-shot RMS is less than 2cm. From years ago, ChO SLR has been the best one in Chinese network, and got the No.10 rank in the global SLR network. It is also an important and high performance station in the International Laser Ranging Service (ILRS). According to the report of ILRS, ChO SLR has the ability of tracking the high orbit satellites, such as Glonass, Etalon and GPS which have orbit height more than 20000km. Based on the Galileo satellite orbit height and the effective area of Laser Retro-Reflectors Array (LRA), the strength of return signal from Galileo satellites will be similar to that from GPS or Glonass satellites. So ChO SLR has the ability of tracking Galileo satellites.

Contents of SLR improvements

Though ChO SLR has the ability of tracking the high orbit satellites such as Glonass, Etalon, GPS and Galileo satellites, it can only get less return signal from above satellites. This is caused by the following causes:

- The coated film of the primary mirror and second mirror are damaged seriously, and now they have low reflectivity.
- The tracking system has lower precision. The mount of the telescope shakes so hard that less data can be obtained from high orbit satellite.
- The energy of output laser pulse is a little low.

Following is the Changchun SLR system structure. The dark color parts are the parts which are to be refurnished for GIOVE-A observation.

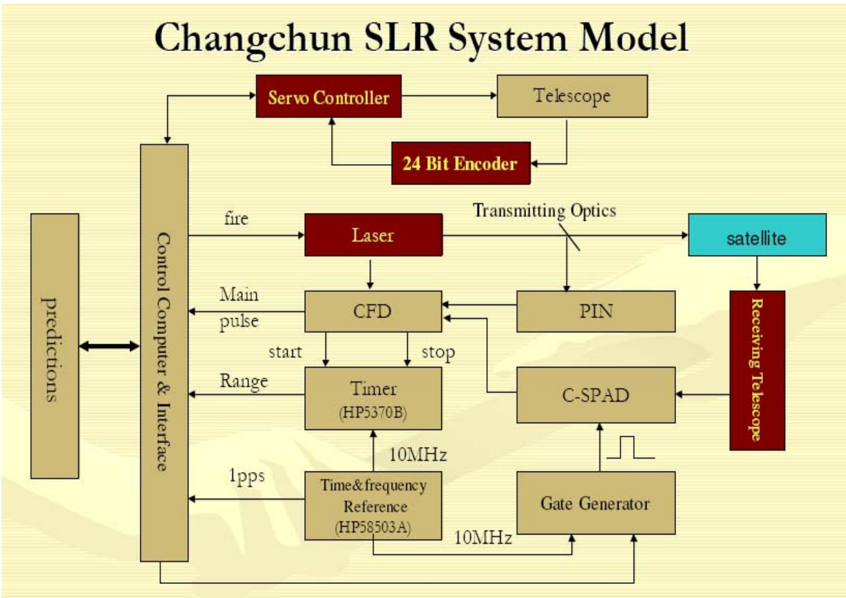


Fig.3. *Changchun SLR System*

If these parts were not improved, it would be very difficult for us to get more data from Galileo satellites and to support a long-term tracking of the satellites routinely. In order to track the Galileo satellites and get more SLR data with high precision, the following things will be done in short-term:

- Telescope. Primary mirror and second mirror of the receiving telescope must be recoated, tested, adjusted and calibrated. This will result in higher transparency of the receiving optics.
- Encoder. A new type photoelectric encoder will be installed in the tracking mount to replace the old one. This will improve the resolution of the angular sensor of the

tracking mount. This can be done in the same period with the telescope modification.

- Servo System. A new type of servo driver will be used to improve the telescope tracking performance. This will heighten the tracking precision.
- Laser System. The old laser components will be replaced in order to heighten the laser output energy up to 70-100mj and improve output stability. This will greatly increase the number of photons reflected back from the satellites.

After the system improvement, the tracking system can have less than 2” tracking precision for high orbit satellites, the output laser energy will be stronger. And these will benefit to improve the return rate and the tracking capability for high orbit satellite of ChO SLR. Finally, the system can execute the Galileo mission and get more data routinely.

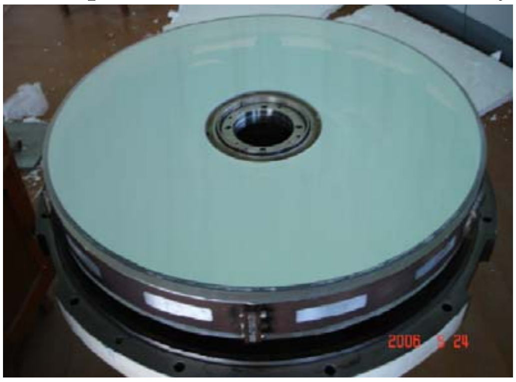
Table 1. *System Specifications*

Label	*Unit name*	*Spec. name*	*Spec*	*Listed in Addendum*	*To be Tested*	*Reason*
M1	Mirrors	Reflectivity of Primary Mirror	≧98% (532nm)	Yes (p17)	Yes	
M2	Mirrors	Reflectivity of Secondary Mirror	≧99% (532nm)	Yes (p17)	Yes	
M3	Mirrors	Reflectivity of 45° Mirror	≧99% (532nm)	Yes (p17)	Yes	
E1	Encoder	Temperature Characteristics	Independent	Yes (p18)	No	Determined by principle (digital electro-optic encoder)
E2	Encoder	Current	Tens of mA	Yes (p18)	No	It’s a middle spec and can be reflected by accuracy
E3	Encoder	Resolution	0.078″	No	Yes	It’s critical spec of a encoder
E4	Encoder	Accuracy	σ≤1"	No	Yes	It’s critical spec of a encoder
E5	Encoder	Sampling rate	500Hz	No	Yes	It’s critical spec of a encoder
S1	Servo	Elevation Max Speed	8°/s	Yes (p18)	Yes	
S2	Servo	Elevation Max Acceleration	$12°/s^2$	Yes (p18)	Yes	
S3	Servo	Elevation Min Speed	<5″/s	Yes (p18)	Yes	
S4	Servo	Azimuth Max Speed	10°/s	Yes (p18)	Yes	
S5	Servo	Azimuth Max Acceleration	$15°/s^2$	Yes (p18)	Yes	
S6	Servo	Azimuth Min Speed	<5”/s	Yes (p18)	Yes	
L1	Laser	Pulse Energy	80mJ	Yes (p18)	Yes	

Performance after improvement

Table 1 lists the specifications to be tested after system refurbishment and the results. All are met the specified value. After recoated, the reflectivity and transparency of the mirrors for 532nm are as follows: primary mirror: 97.29%; second mirror: 99.049%; dichroic mirror: 99.55%; 45°reflector: 99.83%. After system modification, tracking speed and stability of the system greatly improved and output laser energy increased from 30mj to 100mj. Ranging ability increased obviously and points and passes from high satellites increased.

Following are the photos to show the recoated primary mirror, new operation console, laser output on screen, and the encoder system.



The recoated primary mirror

New operation console

Laser output on monitor

New encoder system

Up to Dec.12 of 2006, there are 28 passes of GIOVE-A and 12 passes of GPS-35, -36 to be tracked. Refurbishing work had been finished and acceptance tests were underway. The observations performed by Changchun at the time of the campaign were included in the data set as the data revealed itself to be of high value for the analysis carried out. The geographical location of Changchun (see Figures 4) was of primary importance in providing better laser-ranging coverage of GIOVE-A.

Fig.4. *World map showing geographical distribution of the first GIOVE-A ranging campaign*

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