13th International Workshop on Laser Ranging
"Toward Millimeter Accuracy"

Presentation Summary

Overview of Space Geodesy Techniques (J. Degnan and M. Pearlman)

Scientific Achievements, Applications, and Future Requirements (R. Noomen and S. Klosko)

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13th International Workshop on Laser Ranging
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Abstracts

Overview of Space Geodesy Techniques (J. Degnan and M. Pearlman)

ORAL PRESENTATIONS:

SLR Contribution to the International Terrestrial Reference Frame – Invited

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Since the beginning of the ITRF activities in 1988, the Analysis Centers of the Satellite Laser Ranging (SLR) technique contributed significantly to the International Terrestrial Reference Frame (ITRF). Moreover in terms of datum definition, some SLR solutions were used in the origin and scale definition of the ITRF. In this paper we will review the SLR contribution to the ITRF in terms of network, origin, scale as well as quality assessment. Some aspects related to the optimal establishment of a global reference frame will be examined in case of SLR technique taking into account the reality of its current network configuration. Future ITRF directions will be presented and in particular the inclusion of Earth Orientation Parameters in the ITRF combination. Some combination tests, thanks to ILRS AC's contributions, will be used to discuss the frame parameters.

Scientific Achievements, Applications, and Future Requirements (R. Noomen and S. Klosko)

ORAL PRESENTATIONS:

Time-Variable Gravity Analysis Using Satellite-Laser-Ranging as a Tool for Observing Long-Term Changes in the Earth's Systems – Invited

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Temporal variations in the long-wavelength geopotential have been observed using SLR for the past twenty years. The interannual trends in these estimates have generally been consistent with and attributable to post glacial rebound, in addition to a number of secondary contributors. However, since 1998, J2 began increasing. At present it is not possible to tell whether this aberration represents a change in the long-term rate of change in J2, or whether it is short term in nature. In addition to changes in the mean J2, the amplitude of the annual variation has been changing. This change signifies a large change in global mass distribution whose J2 effect clearly overshadows that of the post-glacial rebound. A number of possible causes have been considered, with oceanic mass redistribution as the leading candidate and core effects as another possible alternative. Several components of the low-degree time series show correlation to known ocean processes. These include correlations between the sectorials and the Southern Oscillation Index, as well as some level of long-term correlation between the Pacific Decadal Oscillation and the observed J2 series. While the exact cause of the recent changes in J2 may not have been formally identified, these results do indicate the usefulness of SLR as a tool to observe long-term changes in the climate. We will present our analysis of the changes in the low-degree spherical harmonics and results of our investigations into the causes.

The SLR Contribution to Precision Orbit Determination in the GPS Era – Invited

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Precision Orbit Determination (POD) of Low Earth Orbiting (LEO) geodetic satellites has long relied on the high accuracy and robust tracking data provided from the global Satellite Laser Ranging (SLR) network. In fact, for nearly three decades SLR has been the primary tracking data for numerous high profile geodetic satellites such as LAGEOS and TOPEX/Poseidon. Over the past decade significant advances in the Global Positioning System (GPS) itself, and GPS data processing algorithms and data distribution, have positioned this technology as the primary tracking to support POD in the new era of geodetic satellites. High profile geodetic missions such as CHAMP, JASON-1, GRACE and ICESat all carry aboard a dual frequency codeless GPS receiver as the primary POD tool. Where does this leave SLR for these modern geodetic missions? Is it anything more than just a backup to the GPS tracking data? The answer is an emphatic yes. Experience with CHAMP and JASON-1 POD has proved the SLR tracking to be an invaluable tool in the calibration and validation of the GPS orbit solutions. POD processing of GPS 1-way measurements is quite complex requiring the orbit determination of over 27 satellites and the estimation of a plethora of system parameters (e.g., clock, ambiguity biases, tropospheric scale biases). The unambiguous, direct SLR measurements provide a high accuracy absolute observation of the orbit. This characteristic has been invaluable in tuning the GPS solutions with their myriad of parameters, and validating their accuracy. Results from CHAMP and JASON-1 GPS orbit solutions will be discussed with a focus on the role and performance of the SLR tracking data.

Contributions of SLR to the Success of Satellite Altimeter Missions – Invited

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Satellite Laser Ranging is well known for its contributions to crustal dynamics research, to establishing the long-wavelength gravity field, and to the monitoring of changes in the major gravity field components. Lesser known is the its invaluable support in the tracking of satellites carrying a radar altimeter. SLR single-handedly saved the entire ERS-1 mission when the PRARE tracking system failed soon after launch. The Geosat Follow-On satellite was to rely fully on GPS tracking, with a laser reflector mounted at the eleventh hour only as a backup. When most of its GPS antennas failed and the receiver rendered the altimeter inoperable, again the laser ranging community came to the rescue. The ERS-2 satellite suffers from an extensive delay in the delivery of its PRARE tracking data. Only because of the rapid turn-around time of the laser ranging data, the ERS-2 altimeter data can be used for near real-time monitoring of ocean currents and El Nino events. Finally, laser ranging has been indispensable in the efforts to accurately calibrate the radar altimeters of ERS-1, TOPEX/Poseidon, and ERS-2.

This presentation will highlight the vital contributions of satellite laser ranging to the orbit determination of satellites carrying a radar altimeter, to the improvement of gravity fields tailored to those missions, and to the calibration of the altimeters.

SLR and the CHAMP Gravity Field Mission – Invited

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Presented by: Ludwig Grunwaldt

The restitution of the CHAMP orbit during launch and early orbit phase in a fast and reliable manner was only possible on the basis of data from two micro wave tracking systems: the skin radar tracking and the high-low GPS-CHAMP SST tracking, yet not calibrated. Soon SLR tracking joined in and the on-board GPS data could be calibrated in the following weeks by help of the SLR data. Nowadays, during the operational phase, SLR data are used to evaluate the precise orbit recovery before solving for the gravity field. Based primarily on CHAMP observations a new class of gravity field models can be computed. The EIGEN-1S was published and its successor, the EIGEN-2S is available in a preliminary version, both with considerable improvements in comparison to former models. As such the long wavelength geoid becomes recoverable from just a few months of CHAMP data only. Following this, variations of the geoid will become detectable.

With the CHAMP mission the fast delivery of SLR data was successfully implemented. The GRACE mission and future LEO missions take benefit thereof. The design of the laser retroreflector on-board CHAMP turned out to be very efficient and was also adopted for the GRACE satellites. Future applications of GPS receivers aboard LEO satellites will tend towards fast to real time availability of highly accurate orbits. SLR will offer a commonly accepted base for calibration and validation. For the full integration of SLR during all mission phases it will be necessary to improve the availability of short latency data or even move towards real time data streaming.

Prospects for an Improved Lense-Thirring Test with SLR and the GRACE Gravity Mission – Invited

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Glenn E. Peterson, Aerospace Corp.

The theory of General Relativity predicts several non-Newtonian effects that have been observed by experiment, but one that has not yet been directly confirmed with confidence is the Lense-Thirring precession of an orbit due to the gravitomagnetic field. Previous analyses are limited by uncertain assumptions regarding the magnitude and correlation of the errors in the low degree geopotential harmonics. Now that the joint NASA-DLR GRACE (Gravity Recovery and Climate Experiment) mission is successfully gathering data, we can examine the expected improvements in the Lense-Thirring experiment using SLR data to LAGEOS-1 and LAGEOS-2. We will also look at other direct and indirect contributions of SLR to the GRACE mission.

Lunar Geophysics, Geodesy, and Dynamics – Invited

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Jean Dickey, Jet Propulsion Laboratory, MS 238-332, 4800 Oak Grove Drive, Pasadena, CA 91109, USA.

Presented by: Jean O. Dickey

Experience with the dynamics and data analyses for earth and moon reveals both similarities and differences. Analysis of Lunar Laser Ranging (LLR) data provides information on the lunar orbit, rotation, solid-body tides, and retroreflector locations. Lunar rotational variations have strong sensitivity to moments of inertia and gravity field

while weaker variations, including tidal variations, give sensitivity to the interior structure, physical properties, and energy dissipation. A fluid core of about 20% the moon's radius is indicated by the dissipation data. The second-degree Love numbers are detected, most sensitively k2. Lunar tidal dissipation is strong and its Q has a weak dependence on tidal frequency. Dissipation-caused acceleration in orbital longitude is dominated by tides on earth with the moon only contributing about 1%, but lunar tides cause a significant eccentricity rate. The lunar motion is sensitive to orbit and mass parameters. The very low noise of the lunar orbit and rotation also allows sensitive tests of the theory of relativity. Moon-centered coordinates of four retroreflectors are determined. Extending the data span and improving range accuracy will yield improved and new scientific results.

Seasonal Changes in the Icecaps of Mars from Laser Altimetry and Gravity

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Laser altimetry of Mars' polar icecaps has provided observations of changes in the height of the icecaps due to the seasonal deposition and sublimation of carbon dioxide from the Mars atmosphere. Observations by the MOLA instrument on the Mars Global Surveyor Spacecraft (MGS) from February 1999 until June 2001 show that both poles increase in altitude by about 1 meter during winter. More snow or ice seems to be deposited at the south pole but it may be slightly deeper in the north. These seasonal icecaps appear to extend down to at least latitude 60 in each hemisphere where it may be less than 10 cm thick. During the same period precise tracking of the spacecraft by the Deep Space Network (DSN) at accuracies of better than 50 microns/sec and 3 meters in range from Earth have shown that the lowest degree coefficients in the gravity field of Mars change seasonally thus enabling the mass of carbon dioxide that is regularly exchanged between the atmosphere and the surface of the planet to be estimated. Using both the volume of material derived from the altimeter and the mass of the material derived from the changing gravity we have concluded that seasonal icecaps of Mars have densities of about 900 kg/m^3. Since the material is carbon dioxide, which has a density of nearly 1600 kg/m^3 in its solid ice form, we infer that the seasonal icecaps are probably formed of thick frost, or that it snows CO2 during Mars' winters.

Future Interplanetary Laser Ranging: Science Goals and Methods – Invited

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Ranging to passive reflectors on the Moon has delivered frontier science measurements of gravitational theory. Tests of relativistic gravity can be carried orders of magnitude further employing laser ranging to the planets. Ranging to Mercury is discussed as example: both the science tests that might be reached and the different ways this ranging could be implemented are considered.

Geophysical Applications of SLR Tidal Estimates – Invited

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The largest time-varying component of the Earth's gravity field is the tidal signal, caused by a combination of the direct gravitational attraction of the Moon and Sun and the deformation of the solid Earth and ocean caused by that gravitational attraction. SLR data have been used to solve for spherical harmonic coefficients of this tidal signal over a wide range of tidal frequencies: semi-diurnal, diurnal, and long-period. The contributions from the direct luni-solar attraction are well known. If the ocean tide contributions can be independently estimated and removed, either using ocean tide models derived from altimetry or from knowledge of oceanic dynamics, the residuals can be

interpreted in terms of solid Earth structure. Particularly promising has been the ability of SLR to constrain anelasticity in the earth's mantle at tidal periods.

Laser Ranging Contributions to Monitoring and Interpreting Earth Orientation Changes – Invited

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The groundwork for a new field in the geophysical sciences -- space geodesy -- was laid in the 1960s with the development of satellite and lunar laser ranging systems, along with the development of very long baseline interferometry systems, for the purpose of studying crustal plate motion and deformation, the Earth's gravitational field, and Earth orientation changes. The availability of accurate, routine determinations of the Earth orientation parameters (EOPs) afforded by the launch of the LAser GEOdynamics Satellite (LAGEOS) on May 4, 1976, and the subsequent numerous studies of the LAGEOS observations, has led to a greater understanding of the causes of the observed changes in the Earth's orientation. LAGEOS observations of the EOPs now span 26 years, making it the longest available space-geodetic series of Earth orientation parameters. Such long duration homogenous series of accurate Earth orientation parameters are needed for studying long-period changes in the Earth's orientation, such as those caused by climate change. In addition, such long duration series are needed when combining Earth orientation measurements taken by different space-geodetic techniques. They provide the backbone to which shorter duration EOP series are attached, thereby ensuring homogeneity of the final combined series.

Monitoring The Origin of the TRF with Space Geodetic Techniques – Invited

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The origin of the Terrestrial Reference System (TRS) is realized through the adopted coordinates of its defining set of positions and velocities at epoch, constituting the conventional Terrestrial Reference Frame (TRF). Since over two decades now, these coordinates are determined through space geodetic techniques, in terms of absolute or relative positions of the sites and their linear motions. The continuous redistribution of mass within the Earth system causes concomitant changes in the Stokes^" coefficients describing the terrestrial gravity field. Seasonal changes in these coefficients have been closely correlated with mass transfer in the atmosphere, hydrosphere and the oceans. The new gravity mapping missions, CHAMP and GRACE, and to a lesser extent the future mission GOCE, address these temporal changes from the gravimetric point of view. For the very low degree and order terms, there is also a geometric effect that manifests itself in ways that affect the origin and orientation relationship between the instantaneous and the mean reference frame. Satellite laser ranging data to LAGEOS-1 and -2 contributed in this effort the most accurate results yet, demonstrating millimeter level accuracy for weekly averages. Other techniques, like GPS and DORIS, have also contributed and continue to improve their results with better modeling and more uniformly distributed (spatially and temporally) tracking data. We will present the results from the various techniques, assess their accuracy and compare them. Finally, we will look into potential improvements in the future, which will likely lead us to even finer resolution and higher accuracy through the constructive combination of the individual time series.

Absolute Earth Scale from SLR Measurements – Invited

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Since the LAGEOS-1 satellite was launched in 1976, the systematic instrument error of the best satellite laser ranging observatories has been steadily reduced. Advances in overall system accuracy, in conjunction with improved satellite, Earth, orbit perturbation and relativity modeling, now allows us to determine the value of the geocentric gravitational coefficient (GM) to less than a part per billion (ppb). This precision has been confirmed by observations of the LAGEOS-2 satellite, and is supported by results from STARLETTE, albeit at a lower level of

precision. When we consider observations from other geodetic satellites orbiting at a variety of altitudes and carrying more complex retro-reflector arrays, we obtain consistent measures of scale, based upon empirically determined, satellite-dependent detector characteristics. The estimates of GM from SLR analysis fall comfortably within the ten ppb uncertainty of that determined from the most accurate alternative from lunar laser ranging observations. The adoption of a value of GM differing by a ppb would result in a difference of a few millimeters in the height definition of a near-Earth satellite. The precision of the estimate of GM from satellite laser ranging has improved by an order of magnitude in each of the last two decades, and we will discuss projected advances which will result in further refinements of this measure of Earth scale.

First results of the French Transportable Laser Ranging Station during the 2002 Corsica campaign for the JASON-1 calibration and validation experiment

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After its phase of improvement and its validation with a triple laser ranging collocation experiment performed at the Grasse observatory, France at the end of 2001, the French Transportable Laser Ranging Station (FTLRS) is presently in Corsica since January 2002. It is the first campaign outside the Grasse observatory for the FTLRS in its new configuration. The aim of this campaign is the validation of the orbit and the altimeter calibration (CAL/VAL) of the JASON-1 satellite at the centimeter level. The mobile station supports the Precise Orbit Determination and geodetic reference operations. The station also participates to the same kind of experiment for the ENVISAT mission. Herein we present first the preliminary results of this campaign concerning the station positioning obtained with a combination of LAGEOS-1, -2, STELLA, and STARLETTE observations, and the comparison with the JASON-1 solution. We also summarize the contribution to the FTLRS for the JASON-1 CAL/VAL phase. This campaign is also very instructive for the next one, which is scheduled in Gavdos (Crete) in 2003.

Preliminary orbit determination of GRACE satellites using laser ranging data

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Presented by: Janusz Zielinski

The GRACE twin satellites provide data significantly improving the model of the Earth gravity field. Except of the autonomous GPS based orbit recovery system they are observed by the laser tracking stations. Laser data can be used for calibration and validation of other systems if the required accuracy could be attained. Presented results offer preliminary estimations of the data quality and the evolution of orbits of two spacecrafts GRACE-A and -B. The study is based on observations taken by the global network during the period May 5, 2002 - May 19, 2002.

POSTER PRESENTATIONS:

Evaluation of potential systematic bias in GNSS orbital solutions

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In order to combine results from different space geodetic technologies it is important to explore potential systematic bias between those results. An example of such comparisons is the use of precise laser range observations to carry out independent checks on the accuracy of published orbits of a subset of the GPS and GLONASS navigational

satellites. Range measurements to two GPS satellites and a subset of the GLONASS satellites obtained by the tracking network of the International Laser Ranging Service are compared in two ways with precise orbits computed by the International GPS and GLONASS Services; by direct comparison of SLR measurements to ranges computed from the microwave orbits, and by comparison of SLR-based orbits to the microwave orbits. Previous studies have shown that in such comparisons it is vital to understand both the potential for systematic range bias induced by the laser reflector arrays and the need for accurate on-satellite positions of the array phase centers. For the GLONASS satellites these parameters are now accurately known for the two different types of array currently in orbit, and the SLR results suggest that systematic orbital bias is minimal. However, for the two GPS satellites, a radial bias of some 40mm persists.

Laser Technology Development (K. Hamal and Y. Gao)

ORAL PRESENTATIONS:

Kilohertz Laser Ranging at Graz

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At present, SLR Graz is ranging to all satellites with a standard Nd:YAG Laser, with 10 Hz repetition rate, using SemiTrain pulses with a total energy of about 30 mJ per shot and a pulse length of 35 ps; we intend to replace this 20 years old system with a diode pumped, solid state laser, operating with 1 kHz repetition rate nominally (10 Hz to 2 kHz specified), with single pulse energy of 0.5 mJ per shot at 532 nm, and a pulse length of 10 ps.

While the present laser system will remain operational for special experiments like MultiColor Ranging etc., the expected advantages of the new laser system are up to kHz return rates for all low satellites, significantly improved return rates from LAGEOS, and same return rates from high orbiting satellites as now; this should map into much better defined Normal Points for all satellites up to and including LAGEOS.

Most requirements to implement such a laser system into the SLR station have been built or installed already during the last years: The Graz Event Timer (E.T.) - operational since autumn 2000 - already allows repetition rates of up to 2.5 kHz; a new Range Gate Generator has been designed and built in Graz to allow kHz repetition rates, while defining the Range Gate with 500 ps resolution.

The necessary budget for this project has been applied for, but we are still waiting for a final decision.

Mechanical measurement of laser pulse duration

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An original interferometric device has been developed, which allows the measurement of the duration of laser pulses in the picosecond domain, with a precision of few percent. This could be a cheap and convenient alternative to the streak-camera methods available today.

Lasers for Multiwavelength Satellite Laser Ranging

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To find the right laser for multiple wavelength millimeter SLR one can consider he NdYAG / SHG / THG, NdYAG / SHG / Raman in Hydrogene/1S/1aS and the Titanium Sapphire fundamental / SHG at different repetition rates. Our optimization of the four wavelengths Raman laser at 1.064, 0.53, 0.68 and 0.45 um gives 60, 20, 7, 2 mJ at 20Hz for 35 psec pulses. The laser setup, conversion efficiencies and the far field beam structure will be displayed. The laser is dedicated for the new Shanghai SLR station.

High-Power, Short-Pulse Microlaser - Power Amplifier System

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Presented by: Peter Moulton

Passively Q-switched Nd:YAG/Cr:YAG microlasers are simple, compact and reliable sources of high repetition rate (100 Hz to 20kHz), near-infrared, sub-nanosecond pulses. To date, low-energy (1 to 10 μJ/pulse) and mid-energy (10 to 50 μJ/pulse) microlasers are commercially available with pulse durations of 600 to 1000 ps. For some applications, for instance, high precision ranging and imaging, higher-energy pulses, as much as 500 μJ/pulse, are required with pulse durations approaching 200 ps. In this work, we report on a prototype of a Laser Transmitter (LT) for the NASA SLR2000 system, generating 335 μJ at 1064 nm with efficient (60%) harmonic conversion to the visible and pulse durations below 400 ps. The LT is based on the use of a MOPA design with a microlaser oscillator and multipass Nd:YVO_4 amplifier. In recent work we have achieved 15-μJ pulses at 1.06 μm from our microlaser, with pulse durations in the green as short as 270 ps.

Improved or Upgraded Systems – Poster Session (F. Pierron and Y. Fumin)

POSTER PRESENTATIONS:

SLR2000 Software: Current Test Results and Recent Developments

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Presented by: John Cheek

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 will be presented along with details of recent additions to the SLR2000 software capabilities and a status of the software development effort.

McDonald Ranging: 30 Years and Still Going

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The McDonald Laser Ranging Station (MLRS), a part of the NASA SLR network, ranges to artificial satellites and to the Moon. It is located on Mt. Fowlkes at McDonald Observatory, near Fort Davis, Texas and was built to replace the original 2.7-m lunar-only system that operated from the late 1960's through the mid-1980's. It is built around a computer controlled 0.76-m x-y mounted Cassegrain/Coudé reflecting telescope and a short pulse, frequency doubled, 532-nm, neodymium-YAG laser with appropriate computer, electronic, meteorological, and timing interfaces. An aircraft radar allows it to operate safely with a single operator. The MLRS's epoch timing system makes all targets equivalent and crew members routinely range to many different targets, from the closest of artificial satellites to the Moon, during a single shift. Over the years it has undergone a vast number of modifications and up-grades, some minor and some major. This poster introduces MLRS personnel and describes the station as it exists now, summarizing some of the more recent changes.

Replacement of the LURE Telescope Controller Using COTS Components Using Commercial Off-The-Shelf Components

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The original 1972 vintage telescope controller at LURE (HOLLAS) had been replaced in March 2000 with a system designed and constructed by a sub-contractor. This system did not meet specifications, and before it could be fixed, the sub-contractor when out of business. A few weeks of research convinced us that a replacement could be designed and constructed using only commercial off-the-shelf components, and could be completed in less time and for less money by using University technicians and engineers rather than going out for bid and engaging another sub-contractor. The performance of the University designed system met or exceeded the original technical specifications. The final product could be used as designed by any telescope system that uses InductosynM transducers, or position sensors that output A quad B signals, and is driven by DC torque motors. This paper will identify the commercial products used, the basic design of the controller, and the performance attained.

System Stability Improvement of Changchun SLR System

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The paper presents some work done in Changchun station to keep and improve the SLR system stability since the system upgrade in 1997, such as the laser improvement, new encoder and servo system, and control system. This work brings and keeps Changchun SLR system at a high level in data quantity and quality during the past several years, and makes the station to be one of the standard and important stations in ILRS.

Improving SALRO Accuracy

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With the evident improved system reliability, attention is being given to the elimination of ranging system biases, to be addressed via these broad categories:

- Systematic errors internal to the ranging system.
- Errors in adopted constants, both internal and calibration targets.
- Positioning of the system invariant point relative to the local datum.
- The relationship between local survey network and the World Geodetic System (WGS).

A series of site surveys will be undertaken soon to confirm invariant point coordinates in the local datum and relative positions of ground targets, while a test is being designed to better characterize the asymmetry in the receive paths.

A new monument is to be established and a GPS antennae distribution facility added to allow calibration of GPS field-positioning instruments at the same time as performing time-transfer roles.

Ultra mobile station FTLRS: Software Control

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French Transportable Laser Ranging Station (FTLRS) is now in a new version, specially designed for the actual mission (Calibration campaign in Corsica for the oceanic satellite JASON-1); the actual software structure and its capabilities will be presented there.

Embedded real-time software control is managed by a remote LINUX station through a TCP/IP link. During tracking, a lot of commands are now available (laser power, telescope tracking, fast swapping between two "near" satellites like Jason/Topex, etc).

Automatic detection of valid echoes is achieved and many hardware survey and test have been added during tracking phase. It is now possible to operate on FTLRS from our Grasse facilities, for software maintenance, improvement test and eventually for tracking (after on site station setup by an operator).

The New MLRS Encoder System: Progress Report

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The McDonald Laser Ranging Station (MLRS), a part of the NASA SLR network, ranges to numerous artificial satellites and the Moon. Successful lunar data acquisition requires very accurate telescope pointing and tracking. At present, absolute encoders combined with physical mount modeling provides 1 arcsecond precision lunar tracking over several minutes and reproducible pointing at the few arcseconds level. However, since the manufacturer of the yoke axis encoder no longer provides bulbs for our model, we need to be prepared to replace the system. The cost of buying a new absolute encoder with the same 0.62 arcsecond precision and the required interface upgrades makes this approach unrealistic. Our solution is to mount a linear encoder tape on the "belly" of the yoke axis, with a stationary read head mounted on the telescope frame. This incremental encoder would send pulses indicating 0.1 arcsecond steps to the existing up-down counter, maintaining resolution for the servo system while improving resolution for the telescope pointing. Although the new encoder requires zeroing after each time the system is powered down, the computer-assisted procedure would require about a minute of work by the observer. This is a reasonable trade off for the factor of 10 reduction in cost. Progress on this work will be presented at the meeting.

Improvements of the French Transportable Laser Ranging Station to high accuracy level

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The very small (300 kg) French Transportable Laser Ranging Station (FTLRS) has been greatly improved the past two years and we'll summarize herein main improvements and different tests performed on the station.

The aim was to reach both high accuracy and stability necessary for JASON1 orbit validation and altimeter calibration experiment. These characteristics are also essential for station positioning adjustment, precise orbit determination, and terrestrial reference frame computation. To reach this performance, many major improvements have been carried out on the FTLRS, they mainly concern:

- laser configuration (wavelength, pulse width, cooling, stability, reliability in hard environments)
- detection package with new optical configuration and C-SPAD detector
- start detection with permanent laser monitoring
- new GPS steered rubidium clock
- software

The success of all these upgrades has been confirmed at the level of few millimeters by the analysis of a collocation experiment performed at the Grasse observatory between the three laser instruments (autumn 2001) and the evaluation of the eight months set of data from the Corsica campaign still in progress.

Upgrading of the Simeiz-1873 SLR Station

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In 1999-2000 the performance of the SIMEIZ-1873 satellite laser station has been greatly improved due to valuable assistance of Michael Pearlman and Daniel Nugent and with the financial support of the CRDF grant UG1-332. A description of the system configuration is shown in Table 1. Now the station is still operating in semiautonomous ranging mode with night tracking, but an upgrading of the SLR software and an installation of the new laser generator are planned in the nearest future. In 2001 more than 550 satellite passes have been tracked with the improved precision. The SLR station is collocated with the permanent GPS receiver and the Crimean VLBI station is 1.3 km away.

Table 1. SIMEIZ-1873 SLR System Configuration.

Mount Configuration	AZ/EL
Laser Type	ND:YAG
Primary Wavelength	532 nm
Pulse Energy	30-80 mJ
Repetition Rate	1 Hz
Receiver Aperture Dia.	1m (70 cm)
Detector Type	PMT (H6533)
Time Counter	HP 5370B (20 ps precision)
Angular sensors	Farrand-Controls (0.4”)

First Laser Ranging Results of the new Potsdam SLR System

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After completing the hardware installation and alignment of main optical components, successful laser ranging has been carried out since summer 2001 using the new Potsdam SLR system. The optical system consists of separated transmit and receive telescopes featuring direct drives for the telescope axes and separately driven, servo-controlled telescope housings. For target calibration, a direct optical link between transmit and receive telescope is established. Special emphasis was put on the efficient PC-based remote control of important system components thus allowing for a strict single-observer operation of the system. Data filtering and management software is build as a client-server database application running under MS-Windows. Data conversion into dedicated formats and data publishing is strongly supported by the internal use of the flexible XML format. Collocation using both the new and the presently operated SLR system (7836) is under way using different satellites. First results using both a Hamamatsu Hybrid PMT and a Silicon Sensor SPAD as a receiver are reported.

System Upgrades of the NASA SLR Network

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The NASA SLR Network has been fully operational in the field for over twenty years. During this time the Network has seen many modifications and upgrades to maintain system operations and more importantly, to increase data quantity and quality. Through a declining budget, NASA continues to ensure system operations and performance are maintained at the highest level. During the last two years, the MOBLAS, TLRS, MLRS, and HOLLAS have received both hardware and software changes to maintain and enhance system operations. This poster paper will detail the upgrades to the timing subsystem, the receiver subsystem, the laser subsystem, the communications subsystem, the mount subsystem, and the processing software of the NASA SLR Network.

Upgrades of Shanghai Satellite Laser Ranging Station

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1. The portable pico-event-timer (P-PET) was brought to Shanghai by K. Hamal and I. Prochazka of the Czech Technical University in August 2001. The satellite ranging experiment with sub-centimeter single shot ranging precision at the Shanghai station was carried out during August 16 to 21, 2001.
2. Three short ground targets were set up in August 2001. The calibration shows that the coincidence of the system delays derived from the three targets is about 2 mm.
3. The system control and diagnosis software has been improved.
4. A set of Vaisala PTU200 meteorological instrument was installed in August 2001.
5. The new observation house for satellite ranging was started to construct in September 2002 and will be completed in March 2003.

NASA SLR Network MCP PMT Upgrade

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Currently, the NASA SLR Network uses the International Telephone and Telegraph (ITT) F4129F Microchannel Plate (MCP) Photomultiplier Tube (PMT). Originally purchased between1985 and 1989, the ITT MCP PMTs were installed throughout the NASA SLR network beginning in 1986. Replacing the Amperex XP2233B PMT, the ITT MCP PMT, coupled with the Tennelec 454 Constant Fraction Discriminator (CFD), greatly enhanced the resolution and accuracy of the NASA SLR Network. After 15 years, the original ITT MCP PMTs have long since lived their useful life. As the original PMTs failed, they were replaced with the spares. Now, these supplementary units are beginning to fail. Efforts to find a suitable replacement for the ITT MCP PMT were begun three years ago, with the first unit being delivered in June of 2002. While the initial purchase of the new MCP PMTs was in progress, investigative efforts continued in an effort to find other manufactures that would meet the needs of the SLR Network. This poster paper will cover the laboratory verification, testing and calibration of the new MCP PMTs for the SLR Network as well as cover the field testing of a developmental MCP PMT from a separate manufacturer.

Timing Devices (E. Samain and P. Gibbs)

ORAL PRESENTATIONS:

ILRS Timing Devices: Specifications, Error Analysis, BEST Calibration Practices

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The time-of-flight measurement device is a key component in satellite laser ranging and is a limiting factor in absolute data accuracy, especially at the one millimeter level. Therefore; optimizing ILRS station timing performance is critical to achieving new scientific objectives.

There are two different types of timing devices in use within the ILRS network of approximately 35 sites; the time interval counter and the epoch event timer. The time interval counter measures the time between two intervals (i.e., laser fire and satellite echo return). The event timer records the epochs of events, from which a time interval between laser fire and satellite echo events is derived. The systematic error sources of both timing principles are very similar; however, the magnitude of the absolute errors can vary significantly depending upon manufacturer specifications, calibration procedures, maintenance practices and the external timebase (i.e. the oscillator).

Currently, more than ≤ of the ILRS sites have time interval units, which were manufactured by either Stanford Research, Hewlett-Packard, or the Latvian University. Less than π of the ILRS sites have event timers, which were manufactured by either Peso Consulting and Thales (formerly Dassault), Electro-Optics Systems, Honeywell Technology Solutions Inc. or EG&G.

Based on manufacturer specifications and ILRS network performance in the areas of single shot precisions and long-term range bias stabilities, pico-second event timers can achieve one mm absolute ranging accuracies.

Range comparison results for various EUROLAS SR timers

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SR timers are very stable, easy to use timing devices. Unfortunately they are non-linear over the full range of measurements required by SLR, although they are very stable in their non-linearily. Each SR timer would appear to have its own individual behavioral pattern. This paper will present comparisons made between SR timers from San Fernando, Potsdam, Graz, Borowiec, Zimmerwald and Herstmonceux against one of the Herstmonceux SR timers.

It will also present the results of comparisons carried out at Graz between the Graz SR timers and the Graz event timer.

Counter Calibrations at Zimmerwald

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The paper describes the Stanford timer calibration procedures performed at Zimmerwald after the Herstmonceux reference calibration during the EUROLAS workshop in March 2002. One of the surprising results was the problem two out of the three Zimmerwald counters showed when driving the counters with an external 5 MHz reference frequency. The calibration values have been applied to the submitted ranges since end of May 2002.

Portable - Pico Event Timer Upgrade

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To reach the millimeter satellite laser ranging accuracy the Portable - Pico Event Timer (P-PET, London) was upgraded to < 3 picoseconds jitter and advanced range gating. The capability to cooperate with the multi kilohertz laser ranging systems was added.

A010 Family of Time interval Counters Adapted to SLR Applications

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Presented by: Kazimirs Lapushka

At present the A010 family includes three models (A011, A012 and A013) of high-precision PC-based time interval counters, which are tailored to meet different special requirements of SLR applications. Specifically, all models are capable of measuring continuously either a sequence of time intervals (up to 4680 in each cycle) between separate Start pulse and Stop pulses or between adjacent Start-stop pulses at the common input. Measurement of time intervals in every cycle is attended by Start pulse timing using internal real time clock (12.5 ns LSD). Measurement process can be controllable both by external signals (input pulse gating, measurement cycle synchronization) and by a user's program.

The counter's models differ mainly by offered single shot RMS resolution (A011 - <40 ps and A012 - <20 ps; both in the measurement range from 100 ns to 209 ms). Compared to the A012, the model A013 offers additional operating mode allowing <10 ps RMS resolution in the measurement range from 1 mcs. Every counter is available both as a ready-to-use instrument (including custom-made options) and a set of hardware-software tools for embedding the counter in more complex measurement system.

Operation of the counters is based on high-speed (<100 ns "dead time") single-channel event timing. Since both Start and Stop events are sequentially timed by the same hardware means, this provides high linearity and temporal stability of time interval measurement under time-varying operating conditions. Some experimental data, which characterize the main features of the counters, are presented.

An ultra stable event timer

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An ultra stable event timer has been designed at OCA (Observatoire de la Côte d'Azur). It includes a vernier, a logic counter, and a 100 MHz frequency synthesis. The event timer has a precision of 2 ps and a linearity in the range of 1 ps. The thermal drift of the 100 MHz synthesis is very low. The dead time between two consecutive events is 10 µs. The device has a RS422 serial port to exchange data. An automatic internal calibration permits to improve the long-term time stability. A prototype of the device is actually working at OCA. A space design is also under study for the space segment of the T2L2 Project (Time Transfer by Laser Link).

POSTER PRESENTATIONS:

Operational Performance of GPS Steered Rubidium Oscillators

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The use of the GPS Steered Rubidium Oscillator as a Time and Frequency Standard for the NASA Satellite Laser Ranging Network had been proposed as early as 1994. This is when initial field-testing was done at the Greenbelt station, operating a custom GPS Steered Rubidium Oscillator concurrently with the stations Cesium Beam Standard (HP 5061A). As this technology made steady improvements, it was decided in May of 1999 to replace all of the networks aging Cesium Beam Standards with the TrueTime XL-DC GPS Time and Frequency Receiver. This poster will describe the basic theory of operation of the GPS Steered Rubidium Oscillator. It will offer examples of actual system performance of the XL-DC units installed at various NASA SLR Stations. Also it will show pre and post Selective Availability performance, as well as laboratory data detailing Allan Deviation and phase performance of various GPS steered oscillators.

Detectors and Optical Chain Components (G. Kirchner and L. Grunwaldt)

ORAL PRESENTATIONS:

New Detection Package at Graz

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At present, SLR Graz is using a simple, straightforward detection package: After the main receiving telescope, the 14 mm beam passes a 0.3 nm interference filter, and is focused on the C-SPAD surface. While this setup is simple, stable and reliable, the 0.3 nm filter usually only allows a maximum of 30% to 40% transmission; it is also difficult to operate it in multicolor schemes.

To improve the total transmission of the optical receiver channel, we are building now a new detection package, which uses dispersion for wavelength filtering as well as for wavelength separation for multicolor operation. Because the effective filter bandwidth will be less than 0.15 nm, and the overall transmission of the receiver package should be more than 70% due to omitting any interference filter, the calculated improvement in signal to noise ratio should be a factor of 4. In addition, the dispersion scheme allows for efficient wavelength separation, again with minimized optical losses.

Time walk compensation of a SPAD with linear photo detection

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The photo detection with a photo diode in the Geiger mode appears promising because of the time stability, the sensitivity, and the simplicity of the device. The transit time between the pulse arrival and the moment when the signal reaches a given detection threshold depends on the photon number in the light pulse. A precise knowledge of this photon number permits to eliminate this time walk if a correction table is known. A device using an auxiliary linear light sensor to measure this photon number coupled with a photo-diode in the Geiger mode for the timing purpose is presented here. This device is designed for both the space and ground segment of the T2L2 (Time Transfer by Laser Link) experiment and could be used in the frame of the satellite laser ranging activities.

The advantages of Avalanche Photodiode (APD) arrays in laser ranging applications

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The Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) is a new lunar ranging campaign aimed at achieving millimeter precision. At the heart of APOLLO is an integrated array of avalanche photodiodes developed at MIT's Lincoln Laboratories. These devices are capable of detecting the arrival of a single photon with high temporal precision (< 50 ps), at detection efficiencies as high as 50%. The integrated array format allows one to create a range profile with each laser shot by detecting multiple return photons, thereby eliminating the strong-signal biasing encountered with a single detector. The array format also preserves spatial information, facilitating

target acquisition and tracking. We are currently using a 4 x 4 array, but the timing system can easily be multiplexed to handle arrays of 10 x 10 elements or larger. Lincoln Labs is presently testing 32 x 32 devices.

SPAD Detector Package for Space Born Applications

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The SPAD detector package for the space born applications is under development for several space missions (T2L2 experiments, transponder, altimeter). The detector is based on the SPAD chips with and active area with 25 um diameter and a newly designed active quenching and gating circuit. The ultra short circuit dead time permits to operate the SPAD in both gated and ungated modes with dark count rates below 10 kHz and timing resolution better than 100 psec. The first results will be presented.

Characterization of a Microchannel Plate Photomultiplier Tube with a High Sensitivity GaAs Photocathode

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Presented by: John Martin

The characteristics of an 18mm photomultiplier tube (PMT) having a high sensitivity GaAs photocathode have been studied. This PMT, the BURLE 85104, uses a dual microchannel plate (MCP) electron multiplier. We report measurements that include standard DC response, single electron sensitivity and resolution, time response, pulse and count rate linearity, and dark counts as a function of temperature. Data is also presented for a gated version of the PMT that has a high-speed anode. The properties of these MCP-PMTs make them well suited for applications such as LIDAR, fluorescence microscopy and chemiluminescence.

Testing of MCP PMTS: Use of Fiber Optic Coupled Gbps Laser Drivers to Create Ersatz Laser Return Pulses

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From an operational point of view, it is important to be able to test the MCP (Micro Channel Plate) PMT (PhotoMultiplier Tube) front end of LIDAR transceivers used in SLR (Satellite Laser Ranging) work. In the day-to-day operation of SLR systems, one needs to have an independent method of ascertaining that the receiver half of the LIDAR transceiver is functioning properly. In addition, the sensitivity and stability of the MCP PMT front end of the LIDAR transceiver also needs to be periodically checked against a standardized source to prevent long and short term errors from insinuating themselves into the production data stream. The creation of ersatz laser return pulses is also useful when developing new LIDAR systems such as NASA's micro-laser altimeter and SLR2k robotic observatory. This paper describes a number of ways of constructing a laser return pulse generator from COTS (Commercial Off The Shelf) parts. In particular, we detail the use of currently available single chip laser drivers – normally employed in fiber optic LAN (Local Area Network) and WAN (Wide Area Network) telecommunication systems – as the "heart"; of the generator. Fiber optics is used to "plumb"; the ersatz laser return pulses together with the optical noise baseline to the output connector of the generator. The use of fiber optics allows one to conveniently fold the optic path within the generator without utilizing mirrors or prisms needed in a free space design and so results in a flatter volume for the generator and obviates the need for enclosing the generator in a light tight box. Since the specifying and ordering of single chip laser drivers and fiber optic components involve considerable amounts of jargon this aspect will also be covered.

Automation and Control Systems (J. McGarry and F. Koidl)

ORAL PRESENTATIONS:

Berne/Herstmonceux Timebias Service

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Individual timebias corrections for all ILRS satellites are calculated at Herstmonceux every 15 minutes from normal point data deposited hourly at CDDIS. They are available to the global network in near real time, on demand, from a dedicated timebias server in Berne.

Intelligent Scheduler, Prioritize in the Fly

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Honeywell Technology Solutions Inc. (HTSI) is developing a new mission planning and scheduling software package for NASA. This new, Intelligent Scheduler, which is based on the HTSI developed scheduler used by the Matera Laser Ranging Observatory (MLRO), will improve on the current NASA SATCOP Mission Scheduling software by allowing the dynamic prioritizing of satellites. The current scheduling scenario assigns static priorities to satellites and schedules the satellites according to those priorities. The new scheduler will allow the priority of a satellite to change according to criteria, such as, a satellite's position and the amount of data recently tracked. Additional features will be included, such as, fine interleaving and sun zone avoidance. The tracking schedule will alternate between a selected satellite and lower priority satellites at given time intervals when using fine interleaving. The Intelligent Scheduler will be a useful tool for generating optimal tracking strategies for the increasing number and variety of satellite missions. This paper will provide an overview of the Intelligent Scheduler and demonstrate its capabilities.

Improvements in the Automation of the Zimmerwald SLR Station

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The paper summarizes the components essential for automated or remotely controlled operation of the Zimmerwald Laser station and describes in more details new components and recently performed improvements.

Automated operational software at Shanghai SLR station

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A real-time operational software interface under Windows95 system at Shanghai station was reported in the 11th International Workshop on Laser Ranging in 1998 in Deggendorf, Germany. For the need of ranging automation and daylight tracking, we developed an automated operational software, based on above software system.

This paper describes the feature of the software:

1. Automated Sun avoidance
2. Real-time correction of orbit prediction
3. Return identification and range gate automated setting
4. Automated system diagnosis

The software has been used in Shanghai SLR station and partly used in Graz.

Infrared Sky Camera -- The Production Model

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A thermal infrared imager for mapping the changing cloud cover over a tracking station has been developed. The instrument produces qualitative results (clear, hazy and cloudy) that have been compared with visual estimations, and the two are found to be in good agreement. There have been no instances of gross disagreements where one source judged the sky to be clear and the other assessed it cloudy, though there were moderate disagreements (clear versus hazy, or hazy versus cloudy) approximately one-third of the time. Following two years of development and testing, a production model has been manufactured which can be shipped to any location, assembled easily and put into operation quickly. This presentation gives an overview of the instrument, explains how it works, and shows sample results.

SLR2000 Closed Loop Tracking with a Photon-Counting Quadrant Detector

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SLR2000 will close the tracking loop using a Photek four quadrant Micro-Channel Plate (QMCP) detector which will provide information to correct the along-track, ranging, and cross-track errors automatically in real time. Analysis and simulation results showing the expected performance of this loop will be presented and will take into account the recent test results of the Xybion mount's tracking abilities. The details of the full tracking loop (both uplink and downlink) will also be given.

POSTER PRESENTATIONS:

Incorporation of GPS Data into HTSI Prediction Cycle to Support the ICESat Mission

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Since the GFZ mission ended in 1999, the ILRS has recognized the necessity to incorporate supplemental satellite position data into the prediction generation process for very low Earth orbiting satellites. The combination of very low satellite altitude and a poor SLR station geometry combines to provide a weak acquisition data product, consequently making tracking more difficult. Current missions, such as CHAMP and GRACE, utilize on-board GPS receivers that provide precise positions to create SLR predictions. The upcoming Ice Cloud and Land Elevation Satellite (ICESat) will be launched into a 600 km orbit in December 2002. Although ICESat will fly at a higher altitude than CHAMP or GRACE, supplemental data will be required to ensure smooth acquisition by the

ILRS stations to support the POD requirements for the mission. HTSI and the University of Texas have developed a process to incorporate the ICESat GPS data, provided by the two on-board BlackJack GPS receivers, into the automated sub-daily SLR acquisition data and delivery process. This poster will describe the mission goals of ICESat and illustrate the efforts of both HTSI and the University of Texas in the generation and distribution of the GPS enhanced, highly accurate acquisition data.

Sun Avoidance Software

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In daylight tracking, it is very important to take effective measures to avoid strong light from the Sun. This paper presents two methods adopted at Shanghai and Graz, with which the specified path can be designed by software and the telescope will move safely around the Sun with a limited angle.

Lunar Laser Ranging (P. Shelus and J.F. Mangin)

ORAL PRESENTATIONS:

Recent contributions to LLR analysis

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Presented by: Peter Shelus

Paris Observatory Lunar Analysis Center (POLAC) has used the Lunar Laser Ranging (LLR) data provided, between 1972 and 2001, by five sites: McDonald (Texas, 3 locations), Grasse (France) and Haleakala (Hawaii). A semi analytical solution has been built for the lunar orbital motion and librations. With respect to prior solutions several improvements have been introduced in the statistical treatment of the data, nutation and libration models and the distribution of the weights of LLR observations. Globally, for recent observations, more accurate than the earlier ones, the root mean square error is within 2 to 3 centimeters in the lunar distance. Special attention has been paid to the determination of the correction to the IAU76 constant of precession and the value of the secular acceleration due to the tidal forces. The positions and velocities of the stations have also been fitted. The lunar theory ELP2000-96 is referred to a dynamical system and introduces the inertial mean ecliptic of J2000.0. The positioning of the dynamical system with respect to ICRS has been performed as well as the offsets of the Celestial Ephemeris Pole. Finally, EOP series (UT0-UTC & VOL) have been determined, between 1987 and 2001, from the LLR normal points of the 2 operational modern stations, MLRS2 and CERGA.

The OCA LLR Station: An Update

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Presented by: Gerard Vigouroux

The OCA station located in southern France shares its activities between the Moon and high-altitude satellites. Since the last laser WS several technical improvements have been studied or implemented, like a an optical device for the correction of the velocity aberration for the satellites. For the Moon we are ready to use the redundant path on the last amplifier of the laser to double the output energy at 800 mJ in 300 ps. A major maintenance on the steering of the dome has been carried out in 2002 to replace the worn-out main rail.

A quality assessment has been performed on three years of range measurements on Apollo 15. The internal consistency per night is excellent, varying between 1 to 15 mm, with no obvious correlation with the number of returns, the number of normal points over each night, the pressure or the lunar libration. Smaller numbers, but with as much scatter, (0.3 to 3 mm) are obtained on the GPS satellites, but with a pulse of only 20 ps. A major effort is underway to automate the observations of the satellites to overcome the chronically under staffing of the station and at the same time increase its efficiency.

In 2001, the station netted 350 normal points on the Moon and more 9500 on the high-altitude satellites. Despite the funding uncertainties and the limited staff we plan to continue the operations on the Moon in the coming years with the main objective of improving the testing of gravitation theories and the comparison of reference frames.

APOLLO: Multiplexed Lunar Laser Ranging

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The Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) is a next-generation lunar laser ranging (LLR) campaign aimed at order-of-magnitude improvements in tests of gravitational physics via millimeter range precision. We will employ the 3.5 m telescope at the Apache Point Observatory (APO), located in southern New Mexico at an altitude of 2800 m. As a result of the large aperture size and excellent seeing conditions, APOLLO expects to detect 2--10 lunar return photon per pulse. Relative background immunity permits operation in daylight and at full moon, resulting in better sampling of the lunar orbit.

We will use avalanche photodiode (APD) arrays as the detector for APOLLO, allowing multiple photons within a single return pulse to be individually time-tagged with high precision. Immediate advantages are shot-by-shot range profiles, as well as guaranteed calibration for each shot. In conjunction with a high time-precision start photodiode, one quickly builds an accurate representation of the convolved laser/detector/electronics temporal response. We describe the hierarchical, multiplexed APOLLO timing system and its implementation using commercial electronics and a programmable logic controller, as well as the various calibration procedures geared toward millimeter range precision. There is no practical limit to the number of channels employed in our timing scheme, allowing an upgrade path to larger APD array formats (10 x 10 or larger).

LLR Developments at Mount Stromlo: Towards Millimeter Accuracy

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Presented by: John McK Luck

LLR in Australia was first conducted in 1977, but there has been no LLR activity for more than a decade. The 1998 relocation of SLR effort to Mount Stromlo, a site considered unsuitable for LLR, seemed to end LLR in Australia. The recent upgrade of Mount Stromlo with high power laser tracking systems and beam processing systems for space research has allowed the feasibility of LLR to be re-considered. An experimental program of LLR is planned for late 2002, specifically to establish the operating parameters required for routine LLR operations. The objective is to obtain an operational configuration for eyesafe, millimeter-accuracy LLR from mount Stromlo. The progress of this effort will be discussed, along with elements of the technical approach.

Station Performance Evaluation (C. Luceri and R. Wood)

ORAL PRESENTATIONS:

MyStationPerformance.COM

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There is a need for standardized; more comprehensive, easily accessible and current ILRS network performance feedback as the ILRS strives toward mm level reliability and accuracy.

Currently, many ILRS sites have limited on-site data assessment capabilities. At some locations, system problems (e.g. equipment problems, data instability, large biases, insufficient data) linger for prolonged periods of time. Conflicting bias information from different analysis centers can also complicate and delay problem resolution.

Our recommended solution to these challenges is the development of a new service, MyStationPerformance.COM. The key features of MyStationPerformance.COM will be:

- Web-based
- Dynamic - near real time analysis (short and long term)
- Comprehensive (i.e., data quantity, RMS stability, bias stability)
- Graphical
- User Friendly
- Interactive

The primary customer of this service will be the ILRS sites (i.e., operators and engineering support). Utilizing this service, sites can expedite the diagnosis of their performance problems, thereby facilitating a rapid resolution and return to acceptable performance.

The ILRS analyst community can also use these site assessment tools to aid in the quick identification of station performance problems.

If effectively used, MyStationPerformance.COM will enable the transition of data quality control from the analysts to the individual stations.

The precise data processing in MCC Analysis Center

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SLR data Analysis Center is a part of the MCC Navigation and Coordinate-time Service. MCC has certain technical capabilities and its own software for the precise navigation and SLR data processing, the monitoring of the GLONASS and GPS signals performance. The MCC Navigation and Coordinate-time Service works continuously in real-time mode.

The products are available from MCC:

- regular daily values of PM and LOD
- bulletins of LAGEOS-1 and -2 SLR data performance
- GLONASS orbits in SP3 format
- the transformation from PZ90 reference frame to WGS-84
- SLR stations coordinates
- low satellites precise orbits (Reflector, Meteor-3M)
- GLONASS/GPS performance characteristics in real-time and a posteriori modes
- precise GLONASS/GPS orbits on the base of navigation receivers data
- etc.

The report contains the analysis of the technical and software capabilities and available precise products of the MCC Navigation and Coordinate-time Service.

The stability of the SLR stations coordinates determined from monthly arcs of LAGEOS-1 and LAGEOS-2 laser ranging in 1999-2001

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The determination of coordinates stability of the satellite laser ranging stations is one of the methods for control the quality of the laser ranging data. This work is continuation of the similar paper about coordinates stability of the all SLR stations in 1999 and 2000. The paper presents results of the coordinates stability determination for all SLR stations in the period 1999-2001 calculated in the ITRF2000 system on the basis of data provided by the LAGEOS-1 and LAGEOS-2 laser ranging. The calculations were performed with the usage of the GEODYN II program. Coordinates of the stations were determined from monthly arcs. Typical RMS of (O-C) values for the monthly orbital arcs was on a level of 1.7 cm. The final stability of the coordinates of SLR stations for all components varies from several millimeters to several centimeters. It was found real movement for two stations Tateyama in 2000 and Arequipa in 2001.

Range Bias vs. Applied System Delay

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Having attained the millimeter-level precision (1-2 mm for normal point, 4-6 mm for single shot), we now have to pay more attentions to the accuracy of laser ranging data. At CRL, weekly reports of 7-satellite residual analysis, producing pass-by-pass range bias and time bias, have been distributed to the ILRS community for 3 years. The post-fit residuals are also useful to check the data accuracy when they are sorted by associated data such as the number of returns per bin [Otsubo, Matera workshop, 2000]. We newly found it useful to choose the applied system delay as a sorting parameter. That is, it is possible to detect potential problems in ranging to terrestrial targets or in subtracting system delay from raw range data. The actual analysis results using recent one year's data of LAGEOS, AJISAI and STARLETTE will be presented.

Absolute and Relative Range Bias Detection Capabilities

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The computed orbit is the final yardstick in accessing ILRS data quality. The absolute accuracy of orbit determination depends ultimately on the quality and quantity of data, but is a trailing (not leading) indicator of 'true' network performance. In order to keep pace and to monitor improvements is laser ranging technology, analysis techniques continually need to be enhanced. This is mandatory for the ILRS is to achieve its vision of mm level accuracy.

Orbital analysis techniques (i.e. collocation, short arc, long arc) have their own inherent strength and weaknesses and will be characterized in terms of absolute and relative range bias detection capabilities. Some new bias detection techniques will be explored and evaluated.

Status of the KACST SLR Program – Past, Present and Future

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Overview of King Abdulaziz City for Science and Technology (KACST) and Space Research Institute (SRI), and how laser ranging fits the charter, in addition to the important role of Saudi Arabia in the global network.

SALRO has realized its re-commission process, is now gearing up to run two operations shifts on a permanent basis. Increasing emphasis is being placed on regular data productivity.

Planning is underway to install a purpose-built active aircraft detection system.

Graphics are presented to show performance over the last few years.

Central to its science charter, KACST will further expand applications through cooperation with the scientific communities within the Kingdom, to include such studies as:

- The landmass – subsidence, gravity etc.
- Orbital mechanics.
- Relativity.
- Earth rotation.
- etc.

Results of the triple laser ranging collocation experiment at the Grasse observatory, France (September - November 2001

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At the Grasse observatory, France, we have the opportunity to have three independent laser ranging stations very close one to each other (about 20 m): a Satellite Laser Ranging (SLR) station, a Lunar Laser Ranging (LLR) station, and the French Transportable Laser Ranging Station (FTLRS). We used this unique configuration to perform a collocation experiment between these three stations from September to November 2001. This experiment was first performed to qualify the new performances of the FTLRS after a long phase of great improvements and before its departure to Corsica for the oceanographic satellite JASON-1 (2001) calibration and validation campaign during the first six-month of 2002. But furthermore, we used this unique configuration to estimate and compare instrumental bias for each station. Herein, we present the main results on the SLR, the LLR and the FTLRS stations obtained with the analysis of this collocation experiment. One of the main results is the validation at the millimetric level for the performances of the FTLRS in its new configuration. Moreover, our analysis shows the consistency at the level of few millimeters between the three laser stations of the OCA, result which demonstrates the strength of the SLR technique. Another important result is the confirmation of a systematical error of 2 cm on TOPEX/POSEIDON laser mean residuals for some European stations such as Grasse and Herstmonceux stations.

System Calibration (I. Prochazka and U. Schreiber)

ORAL PRESENTATIONS:

Use of free surface of liquids in interferometric methods: application to split corner cubes

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A method to adjust and control split corner cubes down to a sub arc-second accuracy is presented, based on an interferometric setup involving use of free-surface of liquids. Such a split corner cube can then be used as a convenient method to adjust parallelism of emission/reception optical axis in laser ranging stations.

Portable Calibration Standard Mission Review

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To examine the millimeter SLR capability the Portable Calibration Standard (PCS) based on P-PET, HP Time and Frequency GPS Receiver, meteo sensor and ground calibration targets was installed at different sites (Graz '97 and '99, WLRS '98, Zimmerwald '98, Herstmonceux '98, TIGO '99, Shanghai '01). The ranging jitter (ground and satellite targets) ranges between 1-20 mm.

Portable Calibration Standard Capabilities

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The Portable Calibration Standard (PCS) has been operated at nine different satellite laser ranging sites within the last five years. The first generation Standard based on the Stanford Research SR620 time interval counter did verify the concept of the Standard, the Portable-Pico Event Timer (P-PET) based version did demonstrate the capability to identify numerous range and time bias sources on the millimeter level. The results from the calibration missions will be presented.

High accuracy short range laser rangefinder for system calibration and installation

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Modern Satellite Laser Ranging Systems are actually able to deliver data with an inherent accuracy of 1 mm and better. Therefore, the position of these systems relative to geodetic markers and the calibration value to the intersection of axis has to be monitored continuously with better than 100 accuracy.

The Deggendorf University of Applied Sciences in cooperation with Micro-Optronic GmbH has developed a rugged handheld rangefinder with a calibrated single measurement accuracy of better than 50 in high accuracy mode. The system guarantees this accuracy up to 5 m distance to any surface and up to 100 m distance to reflectors.

Due to the new patent pending operating scheme the instrument delivers up to 100 measurements per second with 30 single shot stability. With intelligent internal calibration procedures this stability transfers into a extremely high absolute accuracy.

In this paper we will present the operational scheme an first ranging results.

The instrument will be available to the public in spring 2003.

An experimental common detector, coaxial Cassegrain laser telescope and its calibration

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Metsahovi SLR (7806) has used a common detector (PMT) and axially shifted laser beam in a 1-m Cassegrain laser telescope since 1998. As an additional test of the calibration constant the laser beam was positioned in the blind area of the telescope. The beam was transmitted through the secondary mirror axially, using an added 62-mm diameter collimating lens. The return signal from the calibration target, a prism at a distance of 320 m, followed the same path, and continued through the laser insertion mirror to the receiving channel. The start pulse was derived from the laser oscillator, before amplifiers. The delay difference from the regular measurement could be calculated precisely from the telescope geometry. The measurement showed a rms precision of 75 ps, and the calculated calibration constants agreed well within 50 ps. This scheme would be good also for a close target, because no parallactic effects are encountered.

POSTER PRESENTATIONS:

Local Surveys at Goddard

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This poster will provide a summary of the on-going local survey projects and recent results at the Goddard Geophysical and Astronomic Observatory (GGAO). The GGAO fills an important role for the realization of the International Terrestrial Reference Frame (ITRF) because of the four collocated geodetic space techniques, SLR, VLBI, GPS, and DORIS. Precise local survey ties, which determine the relative positions of the collocated space techniques, are critical to the combination of the different techniques in the ITRF solutions. Also the local survey projects at GGAO provide the accurate relative positions of the SLR ground calibration targets necessary to establish the operational calibration ranges used by the SLR system, MOBLAS 7. The poster will include a description of the GGAO survey control network, a description of the survey equipment and methods utilized, and a description of the survey data results and analysis.

Local Survey Relationships to System Calibration and Bias Identification

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For SLR systems that perform system calibrations to external ground targets, it is important to have multiple targets that vary in range and azimuth to help in the identification of system bias, target or station movement. The periodic ranging to multiple terrestrial targets, and the subsequent analysis, can serve as an initial diagnostic tool in detecting potential ground target movement. Local surveys and system ties are also necessary to help monitor the local site stability between system and terrestrial targets. Inaccuracies or movements in survey values to primary calibration targets above tolerances will contaminate calibration data leading to biased satellite data.

Movements in ground targets have occurred as a result of apparent subsurface events affecting the geological stability and characteristics on which these piers are supported. Movements of have been isolated within short periods of time; thus rendering regular monitoring of ground target stability essential to operational activities.

This poster will describe the importance of multiple terrestrial ground targets; the value of regular ground testing to multiple ground targets, and the monitoring of calibration data in the detection of potential target movements. It will also present evidence supporting the importance of performing regular survey to maintain accuracy of system ties. To help describe the potential problems associated with this issue, this poster will provide a summary of recent events at the Goddard Geophysical and Astronomical Observatory (GGAO) and present recommendations for ensuring accurate ground calibration ranges and preventing the loss of satellite range data due to calibration bias.

Station Operational Issues (W. Gurtner and V. Husson)

ORAL PRESENTATIONS:

Creating a Consolidated Laser Ranging Prediction Format

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ILRS Prediction Format Working Group.

Historically, satellite laser ranging, lunar laser ranging, and the few transponder laser ranging experiments have each used their own prediction techniques and formats. With the possibility of many stations being able to range lunar and Mars transponders beginning in the next few years, the prediction format and procedures need to be consolidated and standardized. To this end the Prediction Format Study Group was formed two years ago.

To date, a preliminary format has been produced which consists of state vectors and ancillary data separated in time by some optimal target-dependent amount. These are then interpolated with supplied software to produce range and point angles corrected for light-time and planetary aberrations and relativistic effects.

Experiments are in progress to help finalize the format and algorithms. These include development of an interpolator that will handle variable time separations for the state vectors and experiments with optimal order of interpolation and spacing in time. Development is starting on sample software that can be used at the laser sites to read and interpolate the new format.

The goal is to have this format used in the field by the time of a proposed transponder experiment in 2004.

Operational Issues from the Stations

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Prior to the workshop the ILRS stations have been asked for the factors limiting their performance (both internal ones as well as factors imposed from the network), any factors that significantly improved the performance in recent months or years, and for possible improvements of the network operations. The paper will summarize the answers to this poll.

Operational Issues from an ILRS Central Bureau Perspective

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Three historical weaknesses of SLR, relative to the other space geodetic techniques, are temporal and spatial coverage outages, data latency, and the diversity in the performance of individual sites. The ILRS has done much to improve upon these weaknesses the past several years, but more improvement is needed to achieve mm level accuracy.

The ILRS CB will discuss today's station operational issues and recommendations for improvement in the areas of data quantity, data quality, and ILRS compliance.

Operational Issues from the viewpoint of SLR data analyses

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SLR observations address a variety of scientific investigations, sometimes directly, sometimes in conjunction with other tracking data. In an attempt to feedback to the operational stations the diverse and sometimes conflicting requirements of data analysts, the views of those analysts were sought prior to the workshop on a variety of issues. This paper will summarize the responses and raise questions to prompt further discussion.

Target Design, Signatures, and Biases (G. Appleby and V. Vasiliev)

ORAL PRESENTATIONS:

Retroreflector Array Transfer Functions

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This paper presents some cross section and range correction matrices for satellites such as LAGEOS, TOPEX, and WESTPAC. Diffraction patterns for individual cube corners are also shown. The effects of polarization, and dihedral angle offset are studied. Basic principles of retroreflector array design are discussed for maximizing cross section and minimizing variations in cross section and range correction. Tables of range correction as a function of signal strength for LAGEOS and for target calibration measurements are presented for a particular set of system parameters and detection algorithms.

Difference of LAGEOS satellite response from raw data analysis of the collocation experiment between the Grasse Satellite and Lunar Laser Ranging stations

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We performed a collocation experiment at the Grasse observatory (France) between three independent laser ranging instruments: a Satellite Laser Ranging (SLR), a Lunar Laser Ranging (LLR) station, and the French Transportable Laser Ranging Station (FTLRS). The normal point analysis of the common passes on LAGEOS-1 and -2 satellites showed a systematic difference of 13 mm between the SLR and the LLR station results. To explain this bias, from the raw data and a geometrical analysis, we computed the difference of the LAGEOS satellite ranges due to instrumental differences. So, we show that it effectively exists a dependence between the laser ranging station and the satellite signature, at the level of 3 mm between the two considered stations. Moreover, we have to add a center edge effect of 9 mm for the LLR return photo-detector. Thus, we are able to explain a difference of 12 mm between the two considered stations. We also propose to adopt a LAGEOS center of mass correction value depending on the kind of laser ranging station, dependency especially coming from the difference between a single and a multi photoelectron detection modes. We found that this difference can reach a few millimeters from the one usually used for the laser ranging data analysis.

Recovery of target response function for center-of-mass corrections of spherical satellites

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Accurate center-of-mass corrections for geodetic spherical satellites are expected to contribute to accurate determination of the scale of the earth, i.e., the scale of terrestrial reference frame and the geocentric gravitational constant GM.

We devised a new method to recover the response function of geodetic satellites. Post-fit residual histograms of single photon data were used to overcome ambiguities in the treatment of far-field diffraction effects. Given the response functions, the center-of-mass corrections for LAGEOS, AJISAI and ETALON satellites were derived for various types of laser ranging systems. Among them, the single-photon ranging provides the strongest result because we can produce one unique center-of-mass correction that is always applicable without additional corrections.

International experiment in space for investigation of a novel-type laser retroreflector

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On board of the METEOR-3M(1) spacecraft launched on December 10, 2001, a novel-type laser retroreflector (RR) is installed. The spherical RR uses the principle of an optical Luneberg lens, and has the advantage of minimum target error introduced in ranging measurements. The basic goal of the experiment is to determine the return signal level in real environment conditions.

After the METEOR-3M(1) launching, problems arose with the GPS/GLONASS equipment on board of this satellite, and to provide the necessary precision of orbit determination for the NASA SAGE-III equipment operation, it has been decided to use the international SLR network.

Based on measurement results obtained at the SLR-station near Moscow, estimations have been made of the spherical RR cross-section.

The main center responsible for precision orbit determination (POD) was MCC (Russia). POD was made also by Honeywell Technology solutions, Inc (HTSI). The MCC and HTSI results have practically equal accuracy, and are satisfactory for the SAGE-III mission purpose. Results are presented of comparison between METEOR-3M(1) orbit parameters obtained from laser measurements and regular RF measurements.

The obtained results may be basis for development and engineering of a full-scale ball-lens RR-satellite providing an extremely small target error, which is important for geophysics, geodynamics, and some other scientific areas.

Development and on-orbit performance of moderate-cost spherical retroreflector arrays for the STARSHINE program

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The STARSHINE program provided a successful test of a laser ranging array designed for a spherical satellite and built from standard commercially-available retroreflectors. The basic result from the on-going satellite laser ranging observations is that such a moderate-cost array has satisfactory on-orbit performance for altitudes below 470 km and has also demonstrated to date at least a year-long lifetime. The array contains thirty-one 1 cm retroreflectors arranged for low variability in laser radar cross section for all illumination directions. The number and diameter of the retroreflectors resulted from parametric design studies to minimize both number retroreflectors in the array and the effects of velocity aberration. The experimental verification of the design is based on the observed raw data point density as determined from the field-generated normal points.

Reflector arrangement on H2A-LRE satellite

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We designed the arrangement of cube corner reflectors carried on the Japanese H2A-LRE satellite. 126 reflectors (6 reflectors x 21 sets) are distributed on the surface of the quasi-spherical satellite whose diameter is 50 cm. Half of the reflectors are made of fused silica (optical index = 1.46) whereas the other half are made of BK7 (optical index = 1.52). The optical responses of the two materials are not very different at the beginning but the BK7 is expected to degrade in a short time. We modeled the optical behavior both before and after the BK7 reflectors spoil. The center-of-mass correction is reduced by about 5 mm after the degradation, for all types of laser ranging systems. For users whose interest is in 1-cm precision, a center-of-mass correction of 210 mm can be uniformly applied.

The Atmospheric Neutral Density Experiment: a Mission Overview

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The Atmospheric Neutral Density Experiment (ANDE) is a mission proposed by the Naval Research Laboratory to monitor the thermospheric neutral density at an altitude of 400km. The primary mission objective is to provide total neutral density along the orbit for improved orbit determination of resident space objects. The mission serves as a test platform for a new space to ground optical communications system, the Modulating Retro-reflector Array in Space (MODRAS).

The mission consists of two spherical spacecraft fitted with retro-reflectors for satellite laser ranging (SLR). One spacecraft is completely passive, the other carries three active instruments; a miniature Wind And Temperature Spectrometer (WATS) to measure atmospheric composition, cross-track winds and neutral temperature; a Global Positioning Sensor (GPS); and a Thermal Monitoring System (TMS) to monitor the temperature of the sphere. A design requirement of the active satellite is to telemeter the data to the ground without external protrusions from the spherical spacecraft (i.e. an antenna). The active satellite will be fitted with the MODRAS system, which is a science enabling technology for the ANDE mission. The MORDAS system consists of a set of modulating retro-reflectors coupled with an electronics package, that will telemeter data to the ground by modulating and reflecting the SLR laser interrogation beam.

This paper presents a mission overview and emphasis will be placed on the design, optical layout, performance, ground station, and science capabilities of the mission.

POSTER PRESENTATIONS:

Velocity Aberration

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This paper computes the velocity aberration for a solid, two-dimensional retroreflector moving at velocity v with respect to a stationary laser transmitter. The basic approach is the same as in the paper "Effect of motion of the optical medium in optical location", V.P. Vasiliev, V.A. Grishmanovskii, L.F. Pliev, and T.P. Startsev, 1992. However, the equations are set up differently and give a different answer. The relativistic equations for the addition of velocities are used to compute the velocity of the rays parallel and anti-parallel to the velocity v. The expression obtained for the velocity aberration angle is $2v/c$ with a small second order term that can be neglected. The index of refraction cancels.

Design of a laser retro-reflector for the first satellite ranging mission in S. Korea on an elliptical orbit

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STSAT (Science and Technology Satellite) is the fifth of Korean micro-satellite, which has the laser ranging mission for the first time in Korea. STSATs, formerly known as KITSAT or KAISTSAT, are a series of cost-effective micro-satellites, developed and operated since 1992 by Satellite Technology Research Center (SATREC), Korea Advanced Inst. Science and Technology (KAIST). The primary objective of the STSAT program is to test novel technologies and payloads at low cost (~10 million US$) and a short development period (~ three years). STSATs 1-3 were launched in 1992, 1993 and 1999 and STSAT-4 is due for launch in 2003. They have performed successfully, particularly in mapping the Earth's surface at 13m resolution. STSAT5, scheduled for launch in 2005, has the following specifications: total weight of ~ 100 kg; dimension of ~ 600 ´ 500 ´ 800 mm; sun-synchronous elliptical orbit at 300 to 1600 km. One of its primary mission goals is to verify the performance of the first Korean launcher through precise orbit determination. The verification scenario consists of GPS (global positioning system) and SLR (satellite laser ranging) positioning. In this context, we are developing the laser retro-reflector (LRR) by integrating the experiences of ground laser ranging and laser optics in Korea and, possibly, by collaborating with international partners. The work scope includes also the analysis of SLR data and the determination of the precise position on the elliptical orbit. For this we will utilize our experiences of processing SLR and satellite altimeter data. Finally we will present a brief overview of space program in Korea.

Laser Retroreflector Array (LARA) for IRS Mission

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Indian Space Research Organization (ISRO) is supporting multiple satellites currently for remote sensing applications through its ground stations within and outside the country. ISRO has also plans to launch in the near future advanced remote sensing missions like Cartosat, Oceansat, Metsat etc., which require ground imagery resolutions of the order of 2.5 m. It is not possible to meet this stringent requirement with the present orbit determination using RF tracking. In view of this, a high level task team was set up for advanced tracking systems to improve the orbit accuracy and Satellite Laser Ranging was one of the recommendations by the task team since SLR is the most accurate technique available for observing the orbits of the artificial satellites. Also, ISRO has initiated

space geodetic activity which is a nascent field in India and to pursue this, advanced tracking techniques such as SLR, GPS, PRARE, DORIS, VLBI are required. ISRO is already operating PRARE and GPS stations and addition of SLR will complement data for space geodesy and geo-dynamic studies. ISRO, having a long experience in SLR operation for more than a decade, is an added advantage for this program. Hence, to enable laser ranging to a satellite, laser retro reflectors are to be fitted with the earth facing side of the satellite. This paper presents the design and analysis of the Laser Retroreflector Array (LARA) for future IRS mission. The maximum energy reaching the spacecraft as well the ground receiver, cut off angles, LARA onboard location and other relevant analysis are also brought out.

LAGEOS-2 spin rate and orientation

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Presented by: Roger Wood

The Herstmonceux photometer system (which allows brightness measurements to be made simultaneously with laser ranging) has been upgraded to provide 1ms time resolution. Precise timing of solar glints from the front faces of the corner-cube reflectors on LAGEOS-2 over a two-year period has yielded a detailed record of the slowing of the satellite's rotation and enabled an accurate determination of the precessional behavior of the spin axis.

Atmospheric Correction and Multiwavelength Ranging (S. Riepl and E. Pavlis)

ORAL PRESENTATIONS:

Validation of Mapping Functions

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The present paper focuses on techniques, both numerical and experimental, which are currently used to validate mapping functions relating the zenith path delay correction to other angles of elevation. The paper concentrates on the application of two-color laser ranging data taken with the TIGO SLR module, aiming on a determination of the zenith path delay, as well as the utilization of numerical weather prediction data, which is applied to the estimation of horizontal refractivity gradients. Moreover a comparison of mapping functions with respect to their applicable spectrum of wavelengths is given using raytracing techniques.

Zimmerwald Dual-wavelength Operation: First Experiences

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On August 14, 2002 Zimmerwald started to submit dual-wavelength SLR data collected on 423 and 846 nm using two Hamamatsu photomultipliers. The paper discusses the special hard- und software installations needed for the dual-wavelength operation and presents first results of acquired passes.

Two-color laser ranging with the MLRO system

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The Matera Laser Ranging Observatory (MLRO) has been developed and installed by Honeywell Technology Solutions Inc. at the Center for Space Geodesy "Giuseppe Colombo" (CGS) of the Italian Space Agency (ASI). The MLRO has built-in two-color ranging capability at 532 nm and 355 nm wavelengths with two receiving configurations: either a dual microchannel plate photomultiplier chain or a Hamamatsu streak camera. This presentation briefly outlines the system setup for two color ranging, and describes the first observational results obtained so far on ground targets and satellites.

Atmospheric Refraction at Optical Wavelengths: Problems and Solutions

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Presented by: Erricos Pavlis

Atmospheric refraction is an important accuracy-limiting factor in the application of satellite laser ranging (SLR) to high-accuracy applications. The modeling of that source of error in the analysis of SLR data comprises the determination of the delay in the zenith direction and subsequent projection to a given elevation angle, using a mapping function. Standard data analyses practices use the Marini-Murray model for both zenith delay determination and mapping. This model was tailored for a particular wavelength and is not suitable for all the wavelengths used in modern SLR systems. Using ray tracing though a large database of radiosonde data, we assess the zenith delay models and mapping functions currently available, we discuss the effect of using different types of input data to drive those models and the sensitivity of models and functions to changes in the wavelength and we give some recommendations towards a unification of practices and procedures in SLR data analysis.

Wavelength Dependence of Range Correction

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The diffraction pattern of a retroreflector depends on the wavelength of the incident light. As a result, the range correction for an array with retroreflectors at different orientation angles will be different at each wavelength. This paper shows range correction matrices for LAGEOS at various wavelengths such as 355, 423.5, 847, and 1064 nanometers

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Atmospheric Contribution to the Laser Ranging Jitter

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The contribution of the atmospheric fluctuation - the seeing - to the laser ranging has been investigated. The beam propagation has been modeled using two independent approaches and models. The random component of the atmospheric propagation correction has been found to be well below 10 um for all seeing conditions, beam path geometry and wavelength.

Modification of Laser Ranging Equation

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The goal of this paper is to discuss the atmospheric turbulent effects on the laser beam of the laser ranging, especially for the lunar laser ranging. Considering the laser beam wander and spread caused by the atmospheric turbulence and the distribution of the laser beam, a new form of the laser ranging equation is given. That will guide us to do the real-time tilt compensation for the LLR.

A Database of Atmospheric Refractivities from GPS Radio Occultations

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The launches of the CHAMP, SAC-C, and GRACE spacecraft have started a campaign of dense remote sensing of atmospheric refractivity profiles using GPS radio-occultations of the Earth's atmosphere. These data provide high resolution profiles of refractivities, up to the stratopause, which can be converted into geopotential heights, and atmospheric pressure and temperature as a function of geometric heights.

These data are been made available to the community interested in operational applications. The characteristics and quality, of the data will be described.

Biaxial Rayleigh- and Raman-LIDAR for applications in atmospheric sounding and SLR

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Florian Seitz, Franz Meyer, Technical University of Munich, Nikolaus Brandl, Bundesamt fuer Kartographie und Geodaesie, Fundamentalstation Wettzell, D-93444 Koetzting, GERMANY.

Precise orbit determinations in SLR and LLR require corrections for the contribution of the atmosphere to the effective index of refraction. Despite the fact that the range measurements are obtained consistently, there is a discrepancy of approximately 4cm reported in the comparison between optical and microwave based range measurements for the same GPS satellite target. As a conclusion from earlier work, the knowledge of the water vapor content of the atmosphere at least for some selections of the operation wavelength seems important. To overcome the lack of sensitivity for the measurement of water vapor profiles in the Earth's troposphere by means of remote sensing a biaxial Rayleigh- and Raman LIDAR has been set up on the Fundamentalstation Wettzell, making use of the still existing equipment of a former SLR facility. By operating the station as a Rayleigh-LIDAR its geometrical characteristics and the overall sensitivity of this setup as a LIDAR system could be established and optimized. Observations in the spectral range of 607 nm and 660 nm are probing the troposphere for nitrogen and water molecules. By combining this information water vapor profiles of the lower troposphere were obtained.

POSTER PRESENTATIONS:

Preliminary estimation of the atmospheric nonlinear frequency dispersion and absorption effects on the pulse SLR accuracy

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It is known, that the nonlinearity of the frequency-dependent refraction and absorption of air can evoke in additional errors of SLR, because of changes of the received ranging signal parameters are relatively of the standard calculation methods. Additional group delays, shift of a carrying frequency and her change in a receiving point of the Gaussian laser pulse for SLR are estimated. The estimation is made for "smooth" dispersion curve (just effective UV resonances) without effects of the atmospheric local resonances. It is noted that the shown effects are most important of the multi color SLR for Marini-Murray atmospheric model correction because of the effects depend on a laser ray elevation angle.

Advanced Systems and Techniques (B. Greene and T. Murphy)

ORAL PRESENTATIONS:

SLR2000: Progress and Future Applications

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NASA's new SLR2000 system is an unmanned photon-counting satellite laser ranging (SLR) station. It is designed to autonomously track the full constellation of over twenty SLR satellites, which range in altitude from about 300 km to 20,000 km. Autonomous operation and a common engineering configuration are expected to greatly reduce station operations costs relative to the current manned systems. The system has also been designed with a goal of significantly lowering replication costs. All of the prototype components and subsystems have been completed and tested and have substantially met the original specifications. The prototype system is presently undergoing final assembly and integration in a dedicated shelter with an azimuth tracking dome synchronized to the optical tracking mount. The facility also features a number of security features such as security cameras and sensors designed to detect power or thermal control problems or entry by unauthorized personnel. Field tests are scheduled to begin later this year.

The present paper provides an overview of the various subsystems and test results to date. The meteorological subsystem has operated successfully in the field for over two years and consists of several sensors which measure: (1) pressure, temperature, and relative humidity; (2) wind speed and direction; (3) ground visibility and precipitation; and (4) local cloud cover as a function of station azimuth and elevation (day and night). A "pseudo-operator" software program interprets the sensor readings and makes decisions related to system health and safety and modifies satellite tracking priorities based on local meteorological conditions.

The prototype laser transmitter consists of a passively Q-switched microchip Nd:YAG laser followed by a passive multipass amplifier and nonlinear frequency doubling crystal. It produces about 200 microjoules of energy at 532 nm in a few hundred picosecond pulse at a laser fire rate of 2 kHz. The low energy laser beam is expanded to fill the entire 40 cm aperture of the off-axis telescope to produce an eye safe energy fluence at the exit aperture. The quadrant microchannel plate photomultiplier detects incoming photons reflected from the satellite with a quantum efficiency of 13% and produces a precise "stop" pulse for the event timer, which has a measured timing resolution of 5 psec (corresponding to a range resolution of slightly less than one millimeter). The quadrant detector also generates an angular pointing error for driving the tracking mount servos, so that the central peak of the transmitter

beam falls onto the satellite. During acceptance testing, the mount demonstrated a one sigma RMS tracking precision of one arcsecond or better over a wide range of satellites and orbits.

The system receives updated tracking priorities and orbital predictions from a central processor at the Goddard Space Flight Center via the Internet or a backup modem and transmits satellite range data back to the processor over the same links. The system also transmits data related to the health and safety of the instrument, and, if necessary, various system diagnostics can also be run remotely by maintenance engineers.

Recently, there has been great interest in adapting SLR2000 to serve as the ground terminal for a high data rate, space-to-ground laser communications link, perhaps in parallel with its satellite tracking function. The motivation for, and potential advantages of, such a dual mode system are discussed briefly.

Optimization of the Correlation Range Receiver Parameters in SLR2000

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The extraction of single photon satellite returns from the solar background during daylight tracking relies on the "temporal coherence" of the signal returns and is accomplished in SLR2000 by a "Correlation Range Receiver". In such a receiver, the range gate is divided into a number of equally sized "range bins", and the photon counts in each bin are summed over a sampling period called the "frame interval". The counts in each bin, resulting from many laser fires within the frame interval, are then compared to a "frame threshold". If the count exceeds the "frame threshold", the bin is judged to contain signal whereas, if the count falls below the threshold, that particular bin is deemed to contain only noise. The optimum choice of range bin size, frame interval, and threshold will vary from satellite to satellite and depend also on the current performance of the laser and detector as well as local meteorological and solar noise conditions. Thus, the correlation receiver design must be flexible enough to adapt to changing operating conditions and targets. It must also be able to deal with occasional data dropouts as might be caused by intervening clouds or telescope pointing errors.

In order to optimize the parameters of such a receiver over a wide dynamic range of both signal and noise, the system must be controlled in real time by software that can combine a priori information on the satellite link with real time sensor data. Default values for bin size, frame interval and threshold are computed and tabulated in the software based on a nominal ranging link and solar noise model and the maximum expected range and time biases in the orbit prediction for a given satellite. The measured count rates are then compared to the nominal values and the receiver parameters adjusted via derived algorithms accordingly to achieve a high probability of signal detection combined with excellent noise rejection. These algorithms are based on the maximization of the "differential cell count", which is the difference between the number of cells per frame correctly identified as signal (maximum of one) minus the number of false alarm cells.

The present paper reviews the methodology by which the default receiver settings are optimized and the manner in which they can be updated rapidly in the presence of sensor readings that deviate from their expected values. Numerical results are presented for several key satellites under a variety of atmospheric conditions.

Millimeter Ranging Accuracy - the Bottleneck

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The satellite laser ranging random and systematic ranging error budgets have been analyzed with the ultimate goal of the millimeter precision and accuracy. Several new contributors have been identified and investigated.

Installing TIGO in Concepcion

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Emma Chavez, Raul Escobar, Universidad Catolica de la Santisima Concepcion, Concepcion, CHILE.
Carlos Bustamante, Roberto Aedo, Marco Avendano, Gonzalo Remedi, Universidad Bio Bio, Concepcion, CHILE.
Oscar Cifuentes, Instituto Geografico Militar, Santiago, CHILE.

During the last year the Transportable Integrated Geodetic Observatory (TIGO), and amongst it the SLR module, was in stand by mode for the shipment to Concepcion, Chile. The negotiations of the previous years led finally to a diplomatic note exchange aiming at the joint operation of TIGO in Concepcion. Apart from the BKG the Chilean side formed a consortium in order to share funding for infrastructure and man power, giving means to host TIGO for at least three years. The Consortium consists of the following institutions:

- the Universidad de Concepcion,
- the Universidad Catolica de la Santisima Concepcion,
- the Universidad Bio Bio and
- the Instituto Geografico Militar.

The present paper describes the final updates in the SLR module, as well as the shipment and setup procedure including first results and local survey data providing a connection between the various employed geodetic space techniques.

Overview of Data for the SLR2000 Tracking Mount Performance Testing

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This paper addresses performance specifications provided to the mount manufacturer and final test data sets obtained before acceptance of the mount. Outlined as well are the major dynamic tracking errors identified during the development and testing of the mount and the steps taken by the manufacturer and the customer to correct these problems in order to meet stringent pointing and tracking specifications.

The paper concludes with a comparison of test data sets taken at the factory and similar test sets taken after the field installation of the mount.

Laser Tracking of Space Debris

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Mount Stromlo laser ranging site has tracked non-cooperative objects in space for several years, and has recently extended the technology to the laser tracking of small space debris objects. The technique has strong advantages in the determination of precise orbits for small and unstable objects. The application of laser ranging techniques to typical targets without reflectors, such as space debris, will be addressed.

The MLRO Project: a Status Report

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The Matera Laser Ranging Observatory (MLRO) has been developed by Honeywell Technology Solutions, Inc., for the Italian Space Agency, and installed at the Center for Space Geodesy "G. Colombo" near Matera, Italy. This paper gives a description of the project, outlining the major observational results achieved so far, and discusses possible improvements and future plans.

POSTER PRESENTATIONS:

Photon-Counting Airborne Microlaser Altimeter

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Under NASA's Instrument Incubator Program, we have recently demonstrated a scanning, photon-counting, laser altimeter, which is capable of daylight operations from aircraft cruise altitudes. The instrument measures the times-of-flight of individual photons to deduce the distances between the instrument reference and points on the underlying terrain from which the arriving photons were reflected. By imaging the terrain onto a highly pixellated detector followed by a multi-channel timing receiver, one can make multiple spatially-resolved measurements to the surface within a single laser pulse. The horizontal spatial resolution is limited by the optical projection of a single pixel onto the surface. In short, a 3D image of the terrain within the laser ground spot is obtained on each laser fire, assuming at least one signal photon is recorded by each pixel/timing channel.

The passively Q-switched microchip Nd:YAG laser transmitter measures only 2.25 mm in length and is pumped by a single 1.2 Watt GaAs laser diode. The output is frequency-doubled to take advantage of higher detector counting efficiencies and narrower spectral filters available at 532 nm. The transmitter typically produces a few microjoules of green energy in a sub nanosecond pulse at several kilohertz rates. The illuminated ground area is imaged by a diffraction-limited, off-axis telescope onto an ungated segmented anode photomultiplier with up to 16 pixels (4 x 4). The effective receive aperture is about 13 cm. Each anode segment is input to one channel of a "fine" range receiver (5 cm detector-limited resolution), which records the times-of-flight of the individual photons. A parallel "coarse" receiver provides a lower resolution (>75 cm) histogram of atmospheric scatterers and centers the "fine" receiver gate on the last set of returns, permitting the fine receiver to lock onto ground features with no a priori range knowledge. In test flights, the prototype system has operated successfully at mid-day at aircraft altitudes up to 6.7 km (22,000 ft), with single pulse laser output energies of only a few microjoules, and has recorded kHz single photon returns from clouds, soils, man-made objects, vegetation, and water surfaces. The system has also demonstrated a capability to resolve volumetrically distributed targets, such as tree canopies and underlying terrain, and has performed wave height measurements and shallow water bathymetry over the Chesapeake Bay and Atlantic Ocean. The signal photons are reliably extracted from the solar noise background using an optimized Post-Detection Poisson Filter.

Time Transfer by Laser Link

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The T2L2 experiment allows the synchronization of remote clocks on Earth and the monitoring of a satellite clock with a time stability of the order of 1 ps over 1000 s and a time accuracy better than 100 ps. The principle is based on the propagation of light pulses between the clocks to synchronize. T2L2 will be then able to measure the

performances of ground clocks having a stability in the range of 3 10-15 over the visibility period of a satellite at 700 km. One can also accumulate the data of several successive passages of the satellite to reach a stability in the 3 10-17 range over ten days. T2L2 has been proposed for the Myriade micro-satellite and for the prototype of the Galileo project.