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ADVANCED TECHNOLOGIES IN THE ASI MLRO TOWARDS A NEW GENERATION LASER RANGING SYSTEM

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ABSTRACT

Matera Laser Ranging Observatory (MLRO) is a high performance, highly automated optical and astronomical observatory currently under design and development by AlliedSignal, for the Italian Space Agency(ASI). It is projected to become operational at the Centro Geodesia Spaziale in Matera, Italy in 1997. MLRO, based on a 1.5meter astronomical quality telescope, will perform ranging to spacecrafts in earth-bound orbits, lunar reflectors and specially equipped deep space missions. The primary emphasis during design is to incorporate state-of-the-art technologies to produce an intelligent, automated high accuracy ranging system that will mimic the characteristic features of a fifth generation laser ranging system. The telescope has multiple ports and foci to support future experiments in the areas of laser communications, lidar, astrometry, etc.. The key features providing state-of-the-art ranging performance include: a diode-pumped picosecond (50ps) laser, high speed (3-5GHz) opto-electronic detection and signal processing, and a high accuracy (6ps) high resolution (<2ps) time measurement capability. The above combination of technologies is expected to yield millimeter laser ranging precision and accuracy on targets up to 300,000km, surpassing the best operational instrument performance to date by a factor of 5 or more. Distributed processing and control using a state-of-the-art computing environment provides the framework for efficient operation, system optimization and diagnostics. A computationally intelligent environment permits optimal planning, scheduling, tracking and data processing. It also supports remote access, monitor and control for joint experiments with other observatories.

INTRODUCTION

Ever since the first deployment of laser ranging for space geodetic applications in the mid-sixties, the techniques of Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) have significantly contributed to the advancement of a number of scientific disciplines [Degnan, 1991; Schutz, 1992; Smith, et al., 1993]. Today a network of over 40 globally distributed systems support space geodetic efforts. The primary reason for the success and maturity of the measurement technique is the progressive use of advanced technologies as they evolved [Degnan, 1985; Varghese, et al, 1986; Veillet, et al., 1993; Shelus, et al., 1993]. The adaptation of newer technologies over the years yielded significant improvement in the instrument performance. The quality of the SLR and LLR data has improved by two orders of magnitude during the last two decades. The accurate data over the years coupled with improved scientific understanding through measurement and modeling of phenomenon such as gravity field, tides, and the dynamics of earth's interior allows computation and maintenance of precision orbits to a few centimeters. The precise apriori knowledge of the orbit in turn permits the computation of precise acquisition and pointing vectors for tracking, thus allowing tighter target coupling of the laser beam through smaller beam divergence. The combination of precise pointing, high repetition rate laser systems and high opto-electronic detection capability has also led to vastly improved data quantity over the years.

There are, however, increased demands on laser ranging technique due to competing techniques and fiscal constraints. The future of SLR and LLR will depend on the scientific data quality as well as the cost of producing such data. High quality globally distributed measurement on a number of satellites, supporting various scientific applications, at low operational cost is a critical requirement for the future. Automation and multiple use of the facility are key aspects to be considered for the reduction and distribution of the cost.

In the global network, fiducial observatories play a fundamental role for the high accuracy measurements of geophysical properties. MLRO with its wide target coverage and ranging performance will become a part of a suite of geophysical and astronomical instruments at Matera obtaining critical measurements for a variety of applications. The targets for these measurements include satellites in earth orbits from ~200km to geosynchronous distances, the lunar reflectors (left by Apollo and Lunakhod missions) and deep space mission spacecrafts. With the significant coverage offered by MLRO together with the potential for other astronomical and optical experiments, optimal use of the observatory during the 24 hour daily cycle is essential. The capability to configure, monitor and perform experiments in an expeditious manner without operator intervention is vital to the most effective collection of scientific data. The ability to perform intelligent decision making based on the observing conditions and the critical requirements of various experiments is a highly desirable feature. Thus, the precision, accuracy, reliability and ability to perform automated expeditious intelligent operations are emerging as the system goals a state-of-the-art system. MLRO detailed design is currently performed in the context of these emerging scientific requirements.

The system specification calls for millimeter precision and accuracy on ranging to targets as far as 300,000km. The absolute accuracy of laser ranging is limited by the measuring accuracy of the SLR instrumentation, the refraction model of the atmosphere, and the knowledge of the spacecraft optical reference to the center of mass. The spacecraft induced errors can be significantly reduced through modeling and correcting the laser data [Varghese, 1992; Minott, 1993]. The unique hardware characteristics of the ranging system can be corrected to the submillimeter level to obtain accurate range to the center-of-mass(CM) of the spacecraft. It is estimated that the atmospheric model induced errors can be reduced to the 1-2mm level using multi-wavelength ranging [Abshire, et al., 1985]. A high accuracy receiver system was developed to measure atmospheric dispersion very accurately in "real-time" [Varghese, et al., 1993]; the real-world operational performance of this receive system is currently under evaluation at the NASA 1.2meter telescope facility. If it demonstrates operational success, this feature will become part of the future millimeter system, thus solving the atmospheric model dependent problems. The ranging instrument performance is determined by the laser transmitter, opto-electronic technologies, time measurement system, telescope and the computing technologies. Each of these disciplines is examined in detail in the current design phase to reduce ranging errors and exceed the system specifications.

SYSTEM DESCRIPTION

The laser ranging instrumentation of MLRO incorporates a number of highly desirable features [Varghese, 1992] that is expected of a fifth generation [Varghese, 1994] laser ranging system. The system and sub-system features are carefully chosen to exploit the best of currently available technology. In addition, design and integration of certain hardware components in the system is strategically scheduled to incorporate the best of evolving technologies. Major system hardware features are as follows:

- Multipurpose optical and astronomical observatory.
- 1.5 meter astronomical quality telescope with a high resolution imaging system for astronomy applications.
- Day/night laser ranging capabilities to dynamic targets in orbits of 200 km to geosynchronous distances, the moon and deep space missions.
- Design features to accommodate multi-wavelength ranging to directly measure atmospheric refraction effects.
- State-of-the-art computing and ranging instrumentation
- Easy referencing of telescope axes to external datum to further reference it to the center(CM) of the earth and the latitude and longitude.
- Hazard reduction of radiation on aircrafts using a radar.
- 10-20 Hz Operation at high laser powers; KHz operation using lower powers.
- High resolution(<2ps) time measurements of all critical times associated with various events.
- Aggregated instrument limited ranging precision of ~2mm and accuracy of ~1 mm.

The system software provides a number of highly desirable features. These include:

- Computational intelligence tools for decision making.
- Sophisticated GUI for expeditious diagnostics and operations monitoring functions.
- Autonomous operation of the system for tracking, instrument calibration and optimization.

The MLRO hardware and software modules are designed at the present time to provide an integrated framework for high performance automated operations. The hardware elements for ranging consists of the telescope, laser, transmit/receive optics, transmit/receive electronics, computing and control, timing, and safety. The 1.5meter aperture Cassegrain telescope has a pointing accuracy of ~1arcsecond and is based on a parabolic primary, hyperbolic secondary and a flat tertiary. It has a truly rotatable/removable tertiary to switch to Coude, Nasmyth or the Cassegrain focal planes for coupling to various instrumentation. The provision to "truly" rotate the tertiary mirror and position it within 1arcsecond allows easy interchange of Nasmyth and Coude foci. A state-of-the-art digital state space control system employing 32bit RISC processors for each axis control ensures smooth tracking and pointing operation while allowing self diagnostics and computer access to the telescope. The telescope jitter of <1arcsec RMS combined with the 1arcsec accuracy after star calibration allows precise tracking of distant targets. Since the observatory will be a multi-experiment research and observational site, safety measures for instruments as well as humans is given prompt consideration in the overall design of the system. The safety features include: radar, flashing warning lights, displays, alarms, video cameras, and computer-inhibited operations.

A diode-pumped picosecond (50ps) master oscillator and flash lamp pumped power amplifiers generate ~125mJ in a 50-70ps pulse at 532nm to provide adequate link especially to very distant targets. This configuration is carefully chosen to address the future possibility of high duty cycle (>KHz) operation. The common Transmit/Receive (T/R) optics and the telescope transfer the laser beam to the target and also couple the retroreflected signal from the target to the detectors in the receiver system. The receive optics assembly couples the reflected light from the polarization discriminating T/R switch to the detectors after spatial and spectral filtering. The spatial filter has an adjustable field of view (FOV) from 1 to 60 arcseconds and its geometrical positioning is adjustable to accommodate defocus and decenter. The precise value will depend on laser beam divergence and background conditions. A CCD camera coupled to an image digitizer analyzes the transmitted laser beam quality; this feature is especially desirable for ranging to very distant targets. The narrow bandpass filter (0.1-0.3nm) allows tracking of the satellites/moon under high background conditions of day or night. The 1.5 meter telescope aperture and the superior optical quality of the telescope allows the coupling of the laser beam to the target at a beam divergence of 1-2arcsec with good wavefront quality. This beam divergence will be maintained for tracking all satellites whose orbits are computed and maintained precisely. The beam divergence control feature will be exercised to expand the beam divergence to accommodate prediction errors or when the initial acquisition was not successful. This is also true when the system attempts to track a newly launched satellite whose ephemeris is not known precisely. The data collected in real-time will be used to compute the short arc and propagate forward the improved real-time pointing information. An intensified CCD camera will optically track sun-lit earth orbiting satellites. It will also acquire lunar craters for ranging to the lunar retro-reflectors. These images will be processed in near real-time to permit target recognition and allow optimal guiding of the laser beam to the retro-reflectors.

The data quality of ranging instrumentation is primarily determined by the T/R Electronics subsystem and therefore, plays a crucial role in determining the overall ranging performance. The opto-electronic detection and measurement of the time associated with each event is performed by the T/R Electronics. Special attention is taken to obtain the highest opto-electronic detection efficiencies (30%) and bandwidths (3GHz). The signal processing bandwidths will match the detection bandwidths to generate the most precise definition of the signal for time measurement process. The time and frequency subsystem is a critical part of the overall system. It provides the critical frequencies (10MHz, 500MHz) and timing (1, 10, 20, 100pps) signals from an ultrastable maser to support the generation of the high accuracy data. A multiple channel, multiple vernier event timer measures the time of occurrence of all critical events associated with each laser transmission to the target. The 28 bit event timer operating at a clock frequency of 0.5GHz measures the time from 100millisecond down to ~2picosecond. This 'local' precise time measurement is referenced to universal time (UT) within the uncertainty of UT. The optical events associated with each frame filtered spatially (1-60arcsecond), spectrally (0.1-.3nm) and temporally (~10-300ns) will provide the highest SNR for collected data. This feature is extremely useful for tracking of very distant targets with low link budget in the presence of high background count rate.

As stated earlier, the computing/control system architecture is partitioned to provide the users with the capability to perform multiple experiments/measurements. The software exercising control of the system and providing automation will be versatile in configuring the system for various applications. The emphasis of software engineering is on the ease of maintainability, upgradability and expandability. This will accommodate future expansion and allow optimal use of the system features and capability. The advanced computing environment in MLRO will permit smooth integration of all control and data related hardware functions and facilitate a very high level of automation. The software domain is divided into (1) man machine interface (MMI), (2) computing/decision making and (3) computing/control subsystems. The primary emphasis of the MMI will be to support monitoring, diagnostics and optimization of the system. The MLRO computer hardware configuration will consist of several state-of-the-art Hewlett Packard computers networked to form an efficient and effective computing environment with significant I/O capability. A VME-based real-time interfacing approach and a POSIX 1003.4 compatible real-time HP-RT operating system are special features of the real-time computing environment. The UNIX based HP-755 workstation permits a state-of-the-art man machine interface (MMI) and supports high end computing. Thus, compute-intensive applications such as GEODYN can be run with relative ease using this computing configuration. This capability is extremely useful for near real-time computing of orbits for improved satellite acquisition and pointing as well as processing the data. Currently, an apriori estimate of the orbit is used to discern the data from noise followed by statistical filtering and polynomial regression. With the ability to compute near real-time orbits from actual laser data, the filtering and data fitting processes can be implemented with greater effectiveness.

The real-time control and data related functions are addressed in the design using modern software engineering practices. Object-oriented programming techniques are conceived to facilitate speed of development as well as improve maintainability. Integrated performance monitoring of all processes constitutes a step toward identifying real-time process bottlenecks and highlight potential problems for scalability in the future. A key aspect of an automated system is also the ability to monitor the performance of the system continuously. Device performance as well as data queue utilization, memory utilization, etc., will be included for routine monitoring.

The system performance to a large extent is monitored by numerial and statistical processing of various process parameters. For tasks involving numerical computation, conventional programming and analysis techniques offer superior speed over that of humans. However, in certain types of decision making problems, straightforward numerical computing alone is insufficient to deduce the pertinent scientific or technical conclusion. This is also true in cases where the problem is extremely complex and intuition is required for reaching decisions. If the exact rules for solving the problem is ill-defined or fuzziness exists such that conventional logic will not suffice to adequately and unambiguously define the answers to the problem, then "intelligent" decision making capability resident within the system will be an asset. Mission planning, scheduling, optimizing, sparse image and data analysis are areas where an expert system or computational intelligence tools(or their hybrids) can significantly offer help. Implementation of such tools are expected to further enhance the automation of operations and speed the evolution of MLRO towards a truly autonomous system. The availability of significant computing power is thus included in the current design of the system for the implementation of these capabilities.

SUMMARY

MLRO project is currently underway with the goal of designing a state-of-the art system. Software and hardware architectures are carefully chosen to meet and exceed the projected specifications. The ability to perform automated intelligent tracking and ranging of dynamic targets at high accuracy will offer vastly improved capability for a number of scientific applications. The significant improvement in the quality and quantity of both SLR and LLR data will further advance the science in all associated disciplines.

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