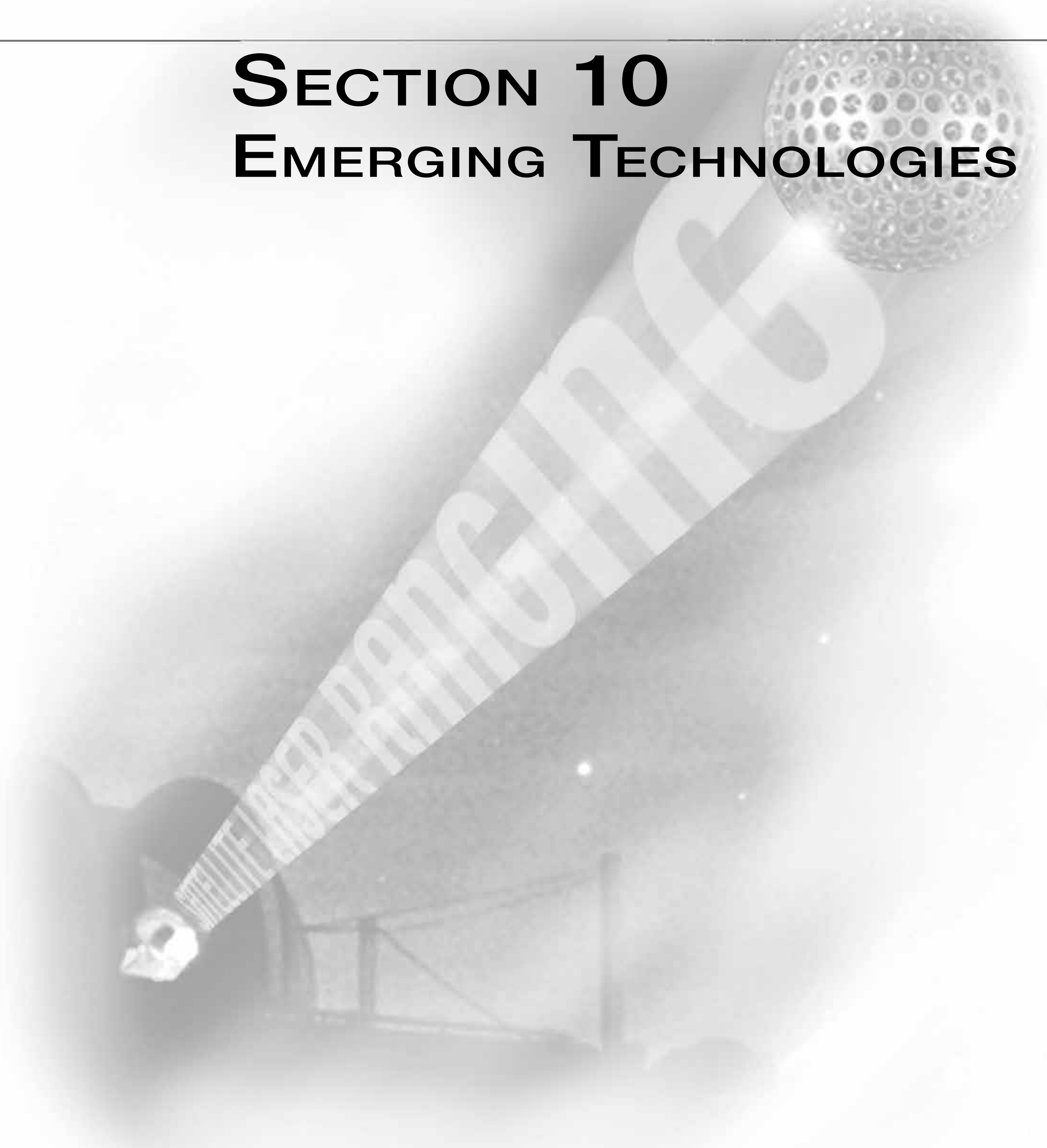
SECTION 10
EMERGING TECHNOLOGIES



SECTION 10

EMERGING TECHNOLOGIES

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INTRODUCTION

This report is largely, but not exclusively, based on the technical papers presented at the 17th International Workshop on Laser Ranging, held in Bad Koetzting, Germany in May 2011. The report also draws on material from external sources. It is not intended as a review of all that was presented, since the online presentations and manuscripts do that adequately. Instead, it is a subjective attempt to organize, summarize and comment on the key technology trends and highlights (hardware only) and to tie key engineering activities into an overall perspective.

KILOHERTZ PHOTON-COUNTING SYSTEMS

The number of kilohertz photon counting systems continues to grow worldwide with new stations in China [Zhang et al, 2011], Korea [Lim et al, 2011], and Finland [Halli et al, 2011].

Chinese colleagues reported on progress at the Kunming SLR station where night ranging to LAGEOS and LEO satellites has been routine and some daylight operations to LEOs has been achieved [Li et al, 2011]. The Kunming station is somewhat unique among kHz stations because of its large 1.2 meter telescope aperture, which is shared by the transmitter and receiver, and a rotating mechanical transmit/receive switch (shutter) which generates a nominal 1003 Hz synchronization pulse, protects the SPAD detector from laser backscatter, and allows the satellite returns to reach the receiver. Comparable upgrades have been implemented at the other Chinese stations, and additional technical and performance details on the Changchun kHz station were presented in several posters [see for example, Liu et al, 2011].

Austrian researchers from the Graz station [Kirchner et al, 2011] have been investigating, both theoretically and experimentally, the feasibility of operating at laser repetition rates greater than 2 kHz, e.g. 10 kHz. The principal barrier is a lower SNR at higher rates due to reduced laser pulse energies and increased solar, SPAD, and laser backscatter noise from the atmosphere. Their early results suggest that the number of satellite returns per second at 10 kHz increases for LEOs, is only marginally higher for LAGEOS, and remains largely unchanged for HEOs. The data increase is greatest at satellite PCA.

COMPONENTS

Detectors

Czech researchers [Prochaska et al, 2011] reported on a number of improvements which included a new SPAD detector designed for multi-kHz operations having a 3.5x lower dark count rate, faster rise and fall times under 150 psec, and reaching sub-mm stability in a few tens of nanoseconds. They also described a new APD start detector and discriminator providing a fast NIM output and a fall time of less than 100 psec.

Precision Timing

Czech colleagues [Prochazka et al, 2011] also reported on a “sub-picosecond” timer based on SAW filter excitation. Their device exhibited only + 4 fsec instability over a 3 hour period. They also discussed the advantages of new low temperature drift cables, such as the Phase Track 210 and LDF50, for achieving high timing stability in the absence of tight active temperature controls. Stability is less than 50 fsec/oK/m or a factor of 100 better than standard coaxial cable.

Latvian researchers reported that their latest Event Timer, Model A033-ET, has been commercially available since 2010 with 10 units delivered as of the Workshop [Artyukh et al, 2011a]. Single shot RMS resolution is in the 2.5 to 3 psec range with a temperature stability less than 0.5 psec/oC and a dead time of 50 nsec. The devices are suitable for both conventional and kHz systems. Current development efforts are focused on: (1) increased stability via temperature compensation and fast and robust calibration; (2) a more compact design and faster operational speeds via integration of all digital functions into one FPGA, use of higher clock frequencies and high speed interfaces (USB3, PCle, Ethernet 1G, etc.); and (3) more user friendly interfaces [Artyukh et al, 2011b].

Laser Transmitters

Picosecond, Kilohertz Lasers

Representatives from High-Q lasers (Austria) and Innolas (Germany) provided a summary of their current offerings in sub-nanosecond lasers [Schmidt et al, 2011]. The laser diode-pumped High-Q picoregen HE produces a highly stable 3.2/1.7 mJ per pulse at 1064/532 nm at a 1 kHz rate. The diode-pumped Spitlite Pico produces 12/6 mJ per 8 psec pulse at 1064/532 nm at a 1 kHz rate. At 2 kHz, the output energies are approximately halved and more than doubled when operated at 100 Hz.

NASA researchers described a nominal 1 mJ laser (non-eyesafe) operating at 2 kHz and 532 nm which uses a regenerative amplifier seeded by a Bragg-reflected short pulse diode laser emitting at the nominal Nd;YAG wavelength of 1064 nm. The laser is compact relative to commercial systems having comparable characteristics and is being tested in NASA’s Next Generation Satellite Laser Ranging (NGSLR) system to enhance NGSLR tracking of GNSS satellites [McGarry et al, 2011]. The pulsewidth can be changed through the use of different diode seeders. The difficulties encountered when tracking GNSS satellites and possible means to overcome them were enumerated by the Herstmonceaux group [Wilkinsonson, 2011]. Recent successes in tracking very high altitude satellites during the day with the new 1 m aperture COMPASS SLR system were described by Chinese colleagues at the Shanghai Observatory [Zhang et al, 2011].

Chinese and Korean researchers have installed kHz lasers built by Photonics Industries in the United States [Zhang et al, 2011]. Their RG series of kHz picosecond lasers, introduced in 2010, produce 25 to 50 psec pulses with energies up to 3 mJ at 532 nm.

MULTI-WAVELENGTH RANGING

After a several year hiatus on multi-wavelength ranging activities and atmospheric refraction modeling, there appeared to be greatly renewed interest in the subject at the Bad Kotzting Workshop, where four relevant papers were presented. Atmospheric errors above 20 degrees elevation were deemed to be at the sub-cm level when the Mendez-Pavlis model is used [Reipl and Pavlis, 2011]. The authors also reported on an effort to take into account horizontal gradients via a Refraction Server, which uses 3D ray tracing and global atmospheric grid data. The only kHz two-color system, SOS-W, is scheduled to be completed by the end of 2011 and will use a 1 kHz, dual wavelength (849.8 nm and 424.9), SESAM mode-locked, Ti:Sapphire laser generating pulsewidths of 40 psec and energies of 1.5 mJ . Favored satellites for two-color measurements are Starlette and Stella due to their near-single cube response and sufficient link to track down to 14 degrees elevation.

Austrian colleagues have proposed an expanded atmospheric refraction model which adds ray curvature and water vapor effects to the usual dispersion contribution [Wijaya et al, 2011]. The authors further conclude that the required accuracy for dual wavelength SLR measurements of atmospheric refraction far exceeds the current state-of-the art. Australian researchers (Greene et al, 2011) disagree with the latter assessment and have proposed a four beam, 100 Hz, dual wavelength system which they believe is presently capable of absolute range accuracies of 3 mm with 1 mm possible in the near future.

The German/Chilean TIGO/SLR team reported on long term two color ranging and calibration activities at Concepcion using a 100 Hz, ultrashort pulse (30 psec), frequency doubled Ti:Sapphire laser oscillator/ regenerative amplifier operating at 847 and 423.5 nm.

LUNAR AND INTERPLANETARY RANGING

Lunar Laser Ranging (LLR)

Following a brief review of the history of LLR and it's impact on our knowledge of the Earth/Moon gravity field interaction and general relativity [Muller, 2011], the status of the 3.5 meter APOLLO LLR system was reviewed along with recent discoveries [Murphy, 2011]. In addition to substantially outpacing all previous data collection rates, APOLLO can range during Full Moon, routinely achieves few mm precisions, and often records multiphoton returns from the lunar reflectors. Experimental results to date produce greater than 15 mm residuals when compared to theory and suggest that several few mm physical effects must be incorporated into current LLR model. An order of magnitude reduction in signal strength from expectations has been largely blamed on retroreflector degradation due to dust.

Japanese colleagues have introduced a 10 W, nanosecond pulse, 2 kHz laser into their 1.5 m aperture station at Koganei in preparation for future high power LLR experiments [Kunimori and Ohi, 2011].

Interplanetary Laser Transponders

Transponder experiments carried out to date or in the proposal stage were summarized at the opening of the transponder session [Degnan, 2011]. Both two-way and one-way experiment configurations were discussed. It was concluded that the physical size, weight, and accuracy of future interplanetary transponder experiments will benefit greatly from current SLR photon-counting technologies, such as:

- Multi-kHz, low energy, ultrashort pulse lasers (10 to 300 psec)
- Single photon sensitivity, picosecond resolution, photon-counting receivers
- Automated transmitter point ahead and receiver pointing correction via photon-counting quadrant detectors (e.g. NASA's NGSLR).

German colleagues at the Wettzell SLR station summarized the results of their AltiDemon transponder simulation experiment [Schreiber et al, 2011] fashioned after a simulation concept presented at an earlier workshop and later published [Degnan, 2006, 2007].

German and French representatives discussed a failed proposal to the ESA Cosmic Vision Program for a transponder mission to Mars labeled GETEMEE (Gravity, Einstein's Theory, and Exploration of the Martian Moons' Environment). The experiment targeted Mars and its moons, Deimos and Phobos. If approved, the onboard laser, derived from the ESA Mercury Bepi-Colombo Laser Altimeter effort, would have made altimetric measurements to the lunar surfaces and participated in two-way Earth-Mars transponder measurements.

Lunar Reconnaissance Orbiter (LRO)

NASA representatives [McGarry et al, 2011] described results from the first operational one-way laser transponder mission. Ten SLR stations in the ILRS network have ranged to NASA's Lunar Reconnaissance Orbiter (LRO) in orbit about the Moon, accumulating about 1078 hours of data before the Bad Koetzting Workshop in May 2011. The light was received by a 2.5 cm lens mounted to the microwave antenna used to communicate with Earth and then transferred by fiber to one of 5 receiver channels of the Lunar Orbiter Laser Altimeter (LOLA) which in turn recorded the time of arrival in the spacecraft time reference. The LR data was used to determine the onboard clock drift rate and aging with the ultimate goal of a more accurate lunar orbit [Mao et al, 2011]. In many instances, multiple stations (up to 4) ranged to LRO simultaneously thereby permitting attempts at geometric solutions for spacecraft position. A limited number of two-way transponder experiments were performed using the LOLA transmitter to range to an Earth station.

LASER TIME TRANSFER

French researchers reported on results obtained from the L2T2 experiment, which was launched on Jason 2 in June 2008 [Pierron, 2011]. Seven European and two Japanese stations participated in the second international campaign from June to October 2010. Time comparisons were conducted between a variety of ground-based ultrastable atomic clocks including rubidium, cesium, hydrogen masers, and fountain. Global performance was better than 100 psec over 1 minute of ranging.

Russian colleagues reported on experiments involving three SLR stations (located in Moscow, Altai, and Komsomolsk-on Amur), designed to synchronize onboard GLONASS clocks with ground-based standards [Moshkov et al, 2011]. They expect an order of magnitude improvement relative to the standard RF time transfer technique.

European researchers reported on a new space mission scheduled for 2014, the European Laser Timing Experiment, in which time transfer, at the few picosecond level, would occur between Earth ground stations and Atomic Clock Ensemble in Space (ACES) via both microwave and laser techniques [Schlict et al, 2011]. The experiments would test new generations of atomic clocks including a cesium fountain clock (PHARAO) and an active hydrogen maser (SHM). Fundamental physics applications would include gravitational red-shift, drift in the fine structure constant, and the anisotropy of light. Czech researchers provided a poster presentation on the photon-counting. [Kodet et al, 2011].

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