Section 5:

Emerging Technologies

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Introduction

New and improved technologies for satellite laser ranging and related applications are appearing. The key motivations are higher precision and accuracy, lower costs, higher productivity and new applications. This section of the report is mostly, but not exclusively, based on the technical papers presented at the International Workshops on Laser Ranging and ILRS Technical Workshops held in Potsdam (October 2016), Riga (October 2017), and Canberra (November 2018).

Detectors

The French (Courde et al., 2016) and German (Eckl et al., 2018) groups developed experimental detector packages based on new commercially available InGaAs/InP detection chips. These chips provide photon detection probability reaching 30% at 1064nm and timing resolution of about 20 ps rms. Such efficiency and timing resolution are comparable to the ones of Si based detectors at 532 nm. The use of such a detector in connection to NdYAG fundamental wavelength of 1064 nm in LLR is providing more than factor of 5x in energy balance in favor of InGaAs/InP.

The Chinese (Honglin Fu et al., 2016) group presented the first successful application of superconducting nanowire photon counting detector in LLR and space debris laser tracking. The superconducting detectors provide very high photon detection probability from visible to infrared wavelength, almost negligible dark count rate and high timing resolution. The challenge is a limited active area diameter, fiber optics signal coupling along with necessary cryo – cooling of the detector.

The Czech group (Prochazka et al., 2017) reported on a number of improvements of existing single photon detector packages optimized for SLR. The new version using the 200um diameter Si chip enables laser ranging with a single shot jitter as low as 10 ps RMS on a single photon signal level. Its effective dark count rate is typically 10 kHz for kHz gate rates. The key improvement of the detector version is also its long-term detection delay stability and its extremely low thermal dependence. The detection delay dependence is lower than 30 fs/K over the entire temperature range of -55… +55°C. The ultimate precision and long-term stability characterized by Time Deviation (TDEV) is better than 80 fs for integration times of hours.

For laser time transfer applications, the new generation of SPAD detector packages were developed for both ground and space segments. These devices were optimized for maximum timing stability within a broad temperature range. A new fully passive compensation of detection delay temperature dependence was developed. It provides detection delay dependence as low as 20 fs/K. Space qualified detector packages versions are available.

For optical tracking of orbiting space debris, the Czech group (Prochazka et al., 2018) developed a new version of high quantum efficiency photon counting package, which is capable of operation in both gated and cw mode. The gated mode presented before is dedicated for active laser ranging of orbiting space debris. The cw mode enables counting of photons scattered by orbiting space debris as a function of time. The cw mode dynamical range exceeds 3.5 orders of intensity. The light intensity curves enable determination of debris orientation, spin and several other parameters.

Timing Systems

In general, most of the SLR systems did or are converting to event timing concept. This change is enabling higher (kHz) operation rates, better temperature stability and better timing linearity.

The Latvian group continues upgrades of its timing systems A033 (Burak I, 2016), (Bespalko V, 2018). The main improvements are the increased maximum reading rate (30k to 1M readings per second depending on device version), single shot precision of several ps rms, temperature stability and non-linearity both on fraction of ps level. Epoch timing systems from this group are used at SLR systems worldwide (> 80 installations).

The Prague group continued in optimization of its New Pico Event Timer (NPET), which provides sub-ps timing jitter and femtosecond long term stability. The space qualified version is under development (Westin J, 2018) for applications in laser time transfer and similar space applications.

New SLR Station Concepts

A new concept of mounting whole laser units directly on the telescope has been tested successfully in Graz; both pico-second lasers and a more powerful space debris laser have been mounted on the telescope, and demonstrated the advantages of such a configuration. Considering the ongoing laser developments, it is expected that in the near future this concept will replace Coudé path systems.

The Stuttgart group demonstrated SLR with significantly higher repetition rates, up to 100 kHz; although such concepts still require some upgrades/changes in actual procedures, they offer significant advantages in terms of high data rates, high output/fast tracking of large numbers of targets. In addition, this offers advantages for automatic tracking and ranging.

Future Plans

Space Debris Laser Ranging

Most new SLR stations – planned or just being set up now – include a space debris laser ranging capability; several existing stations are also upgrading for that capability. Together with increasing numbers of stations with bi-static extension, this creates a network which can overcome the usual weather problems.

Tests for full daylight and blind nighttime debris laser ranging are ongoing.

Laser Time Transfer

Several space agencies are preparing or planning the laser time transfer ground to space. These measurements are prepared in connection with several space missions dedicated to high quality oscillators operating in space. The European Space Agency is preparing the ACES mission with the European Laser Timing module on board (Schreiber K.U. et al., 2018). The mission is under preparation for launch in 2021. The European SLR network is being prepared for participation in laser time transfer missions. The one-way delays of four European SLR systems were calibrated. Their station time scales are expected to be connected via fiber optical fiber network to several optical clock laboratories in Europe. The ACES follow-on mission called I-SOC with improved timing parameters is under preparation now. The performance of the hardware developed for the I-SOC laser time transfer is illustrated in Figure 5-1, where the overall system delay is plotted. The test setup consists of a rather long pulse laser source (Hamamatsu 42 ps FWHM), Start detector, SPAD detector with passive temperature compensation of detection delay and a two channel NPET timing device. The warmup part may be seen. The entire experiment was completed under standard laboratory conditions, no temperature control, etc. The long-term stability of the entire laser time transfer chain of the order of hundreds of femtoseconds over hours of operation may be seen. The stability expressed as Time Deviation (TDEV) is typically 80 fs for integration times of hours. These values illustrate the excellent performance and the long term stability of all the components of the laser time transfer chain including ground (SLR) and space segment.

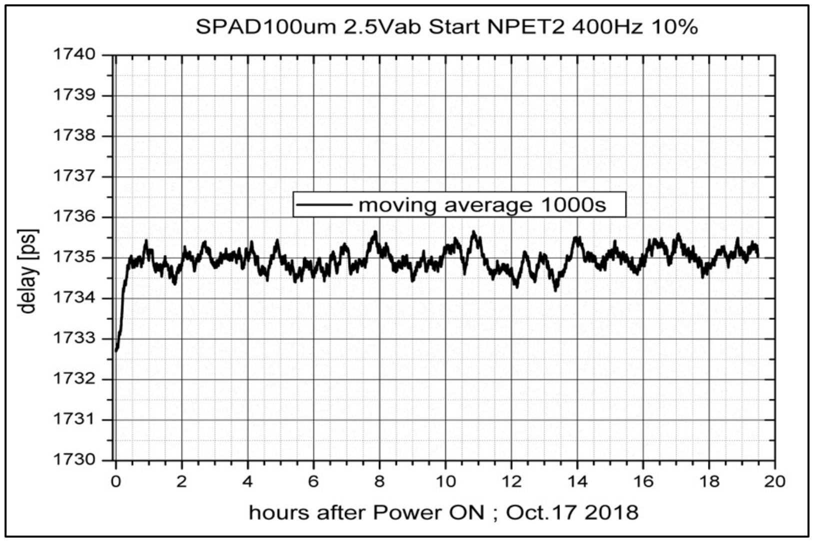

Figure 5-1. Long term stability of laser time transfer chain, I-SOC version 2018, ground tests results.

LIDAR

The high repetition rates, together with single-photon detection, allow simple implementation of LIDAR options as an add-on feature, with minimal effort; this can be useful for aircraft and/or cloud detection, a bonus for automatic SLR procedures.

Autonomous SLR

Autonomous tracking and ranging are already demonstrated in some stations (Mt. Stromlo, Zimmerwald etc.); all planned new SLR stations are implementing such operational procedures. One main concern there is security (internal, but also with respect to external access).

Compact, Eye-Safe, and Intelligent Multidisciplinary Optical Systems

Decades of SLR focused on technologies supporting millimeter accuracy and precision. Most of the process still relies on human operations, which has dependencies that often inhibit optimal operations and maximizing data yield. With the proliferation of satellites in all orbits and a need for dense coverage of the satellites, Cybioms Corporation, Electro Optic Systems, and others are developing systems, which are compact, eye safe, and demonstrating high levels of intelligence in operations for daytime and nighttime operations. This is particularly important when multidisciplinary work happens with such systems, especially in an observatory type environment. With a fusion of sensors, measuring a variety of instrumental and environmental parameters inside and outside of an observatory, the capability could exceed the level of human supervised or human managed operations.

Varghese (2017) reported the use AI for automatic sky detection of cloud coverage during day or night towards optimal tracking. Additional use of recognition technologies will serve to protect equipment in cases of quickly changing weather dynamics such as rain, lightning, etc. Furthermore, all machine activities can be systematically captured that will also allow forensics on any adverse event (if and when it happens). This will be used to augment training of employed AI technology that makes decisions about the health and safety of the system, to ensure smooth operation. One key concern for such automated operations is airspace safety, which needs to be managed with the appropriate selection of wavelengths or a companion safeguard system with ultrahigh reliability and redundancy. As always with any software driven systems, the extent of instrument/system level testing and operations to flush out any behavioral inconsistencies is a major part of the issue.

Cybioms Corporation and Electro Optic Systems are currently exploring a variety of ways to make the hardware of the optical systems compact, highly reliable, eye safe for MHz operations. In this regard, fiber lasers with a push towards 1.5-micron regime coupled with cryo-cooled nanowire technologies for detection is being studied. Beyond SLR, the new optical observatories that we are in the process of establishing will have faint optical imaging (magnitude 23 stars) with Cryo-cooled cameras with an intent to enable debris imaging including GEO.

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