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HartRAO Hartebeesthoek Radio Astronomy Observatory

Development of an integrated timing and photon detection system for the HartRAO Lunar Laser Ranger

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The Hartebeesthoek Radio Astronomy Observatory (HartRAO) in South Africa is currently developing a Satellite/Lunar Laser Ranger (LLR) system in collaboration with the Observatoire de la Côte d'Azur (OCA) and NASA. The station will improve the current LLR network, especially in the Southern Hemisphere. This station will also contribute towards our current understanding of fundamental physics and the Earth-Moon system. To better understand the Earth-Moon system, the measurements made are required to be at sub-centimetre accuracy levels. Timing and photon detection systems are fundamental components which can affect the accuracy of the measurements. We present a design of the timing and photon detection system for the LLR station. The design is modular and will allow addition of a Satellite Laser Ranger (SLR) capability at a later stage. The preliminary design indicates that the timing sub-system should achieve picosecond-level (ps) timing resolution with an Allan deviation at the 10^{-12} level for 1 second and a drift rate of less than 10^{-12} per 24 hours. Errors in timing can be introduced by electronic instabilities, thermal variations and jitter during ranging. Statistical effects during the computation of a normal point (an averaged number of single shots) reduces these errors significantly. Implementation of the proposed timing and photon detection systems will contribute towards high accuracy measurements at sub-centimetre level.

Keywords: *Earth-Moon system, timing system, photon detection system*

Introduction

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) in South Africa is currently developing a Lunar Laser Ranger (LLR) system in collaboration with Observatoire de la Côte d'Azur (OCA) and NASA [1]. The station will strengthen the current network of International Laser Ranging Services (ILRS) especially in the Southern Hemisphere. A better network will deliver better data which will in turn contribute towards a better understanding of fundamental physics and the Earth-Moon system.

The technique of LLR is similar to Satellite Laser Ranging (SLR) and it involves transmitting very short laser pulses at 532 nm wavelength to the retro-reflectors that are on the surface of the Moon. The laser pulses are reflected by the retro-reflectors to the telescope and the time-of-flight is measured. The retro-reflectors on the Moon (Figure 1) were deployed by some APOLLO and Lunakhod missions during the 1960's [2].

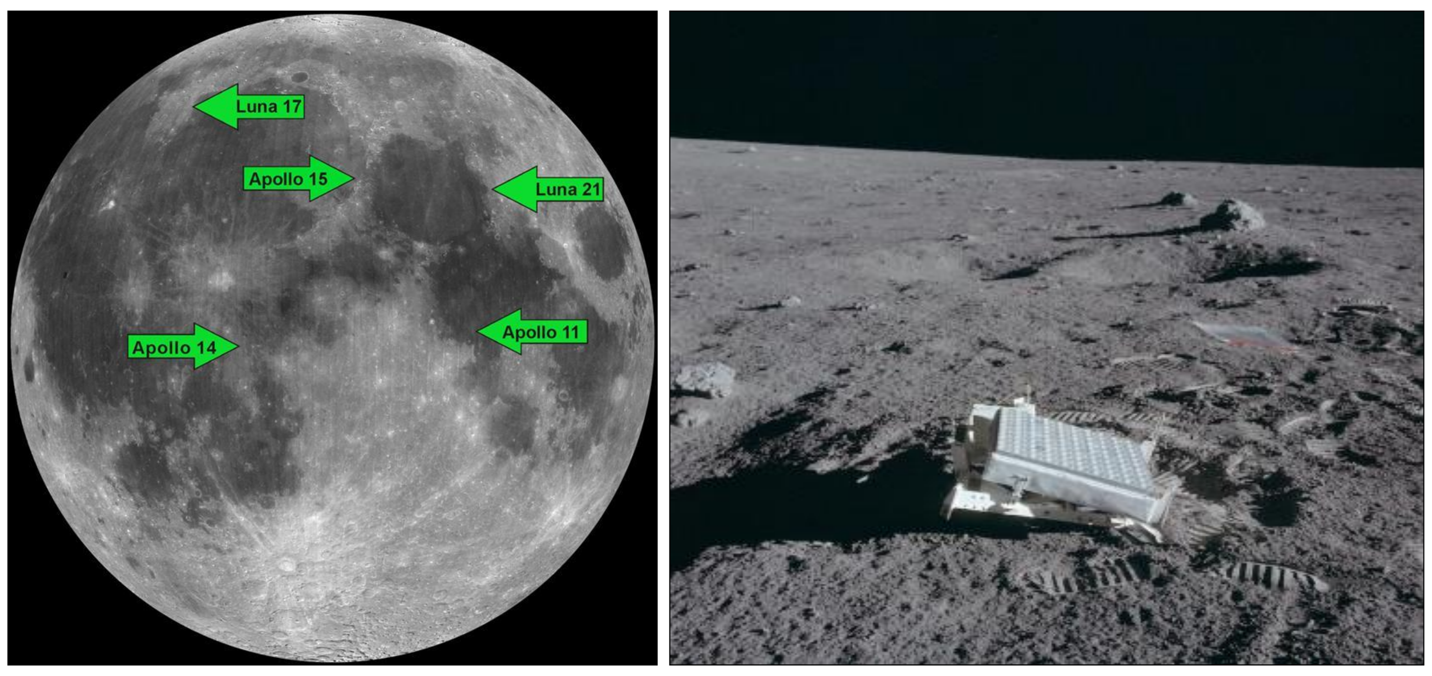

Figure 1. Left: location of the retro-reflectors on the Moon. Right: Example of an array of retro-reflectors from APOLLO 14 on the surface of the Moon (Source: NASA).

The retro-reflectors on the Moon provide us with a laboratory to study fundamental physics and so to better understand the Earth-Moon system. The resulting measured distance between the Earth and the Moon can help us to evaluate the General Theory of Relativity and the time-dependence of the gravitational constant, G. To enable this evaluation, we require observational variables to be measured at sub-centimetre level.

The new station therefore should be able to measure at sub-centimetre level, for both SLR and LLR. These requirements need a specialised system design and configuration of all sub-systems. This project will focus on the design and integration of the timing system, as well as a single-photon detection system. A 1 m aperture Cassegrain telescope, which was donated by OCA, is being converted for this purpose (Figure 2).

Figure 2. The ex-OCA telescope has been refurbish and painted, the mobile housing has been moved to the rear (the structure runs on metal tracks) as seen behind the telescope. The telescope tube has been removed for refurbishment, re-painting and installation of thermal sensors. Both main and secondary mirrors are undergoing re-aluminising.

System Design

A simplified block diagram of the various sub-systems of the HartRAO S/LLR station is illustrated in Figure 3. The system is designed in a modular form and utilises two Nd:YAG lasers operating at 532 nm wavelength. The start pulses from each laser will be detected by start detectors at the laser table. The New Pico-second Event Timer (NPET) will be used to analyse and time tag each individual input and returning signals. The expected calibration precision is <1 mm RMS (i.e., on site pre- and post-calibration). At the moment, the MOBLAS-6 SLR on-site calibration is ~6.5 mm RMS under good atmospheric conditions. The returning photons from the Moon will be detected by a High Quantum Efficiency (HQE) detector (>70%) whereas, the returning photons from satellites will be detected by a Single Photon Avalanche Photodiode Detector (SPAD) with quantum efficiency of about 60% [3,4].

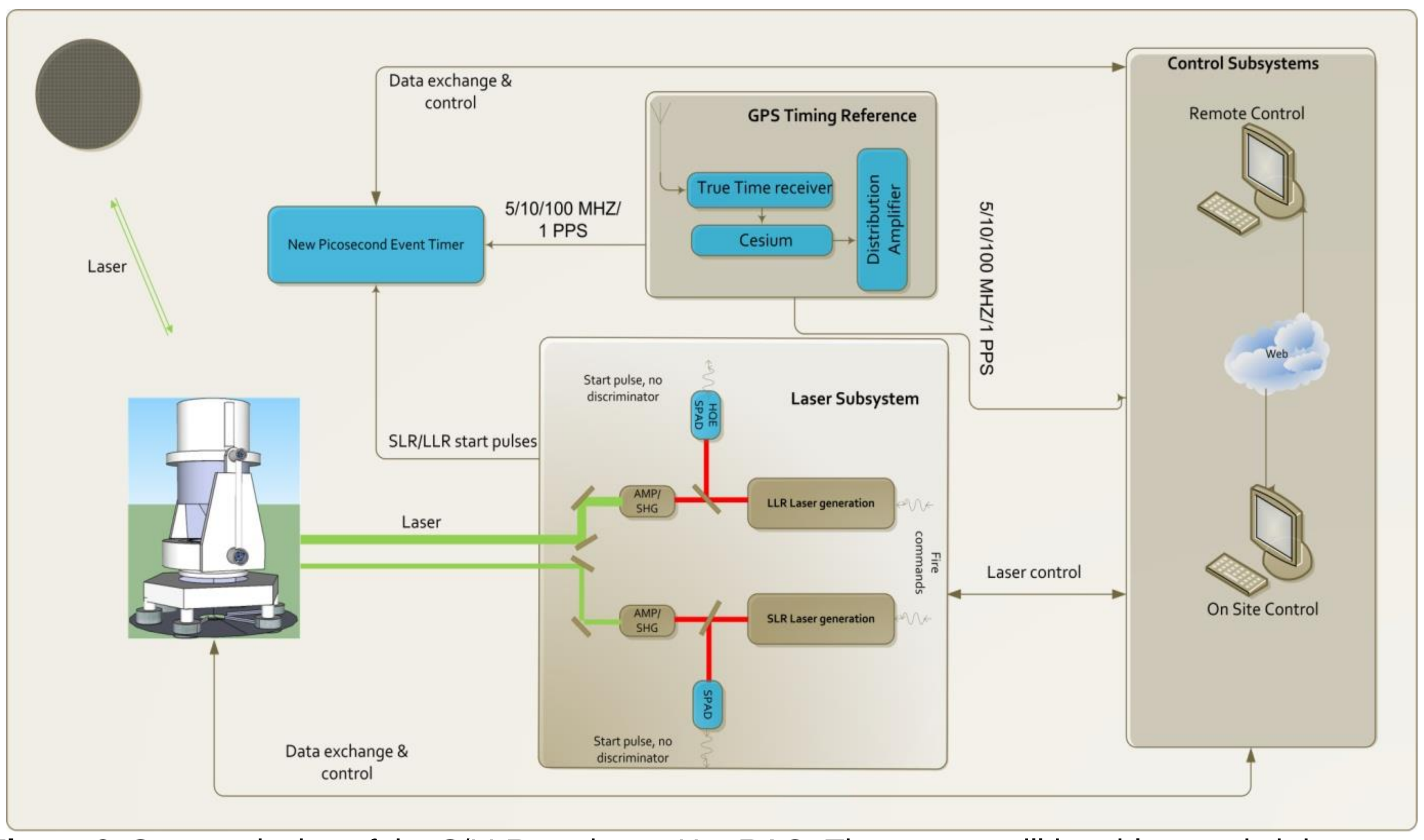

Figure 3. System design of the S/LLR station at HartRAO. The system will be able to switch between LLR and SLR ranging modes.

We plan to use a MicroSemi XLi time receiver as our standard time and frequency reference together with a highly stable Oven-Controlled Crystal Oscillator (OCXO) disciplined by GPS. This system will provide a reference frequency of 10 MHz with high phase stability, an Allan deviation at 10^{-12} level for a 1 second period and a drift rate of less than 10^{-12} per 24 hours. The 10 MHz frequency is multiplied inside the NPET unit to a 100 MHz signal to drive the event timer.

Timing errors are introduced by electronic instabilities, thermal variations and jitter during ranging. Statistical effects during the computation of a normal point (an averaged number of single shots) reduces these errors significantly. Implementation of the proposed timing and photon detection systems will contribute towards high accuracy measurements at sub-centimetre level.

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