N.E.R.C Space Geodesy Facility, Herstmonceux;
Current status and Future Upgrades

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Abstract
The NERC Space Geodesy Facility (SGF) at Herstmonceux, UK features a very accurate and prolific ILRS SLR system, two IGS GNSS receivers and associated environmental monitoring systems. Automatic QC processes continually monitor the quality of all the observational products, the results of which are made available daily on the SGF website. Current funded plans for system upgrade include building an event timer based upon highly accurate timing modules and integration of a KHz solid-state laser system. In the near future plans include a funded proposal to place permanently on site an absolute gravimeter to compliment the space geodesy measurements and make possible new science from the site. In this poster and paper we highlight the current diverse facilities at SGF and outline the future prospects.

1. Satellite Laser Ranging System.

The HERL SLR system remains a very effective ILRS core station, with 8mm single-shot ranging precision to flat calibration targets. This precision decreases to 16mm for LAGEOS observations, which for the strict single-photon operational philosophy is the theoretical level of precision for the satellite. Based on knowledge of the quantum efficiency of the C-SPAD detector (~0.2) it is likely that on average only a single photon is reaching the detector provided that the return rate is less than about 15%.

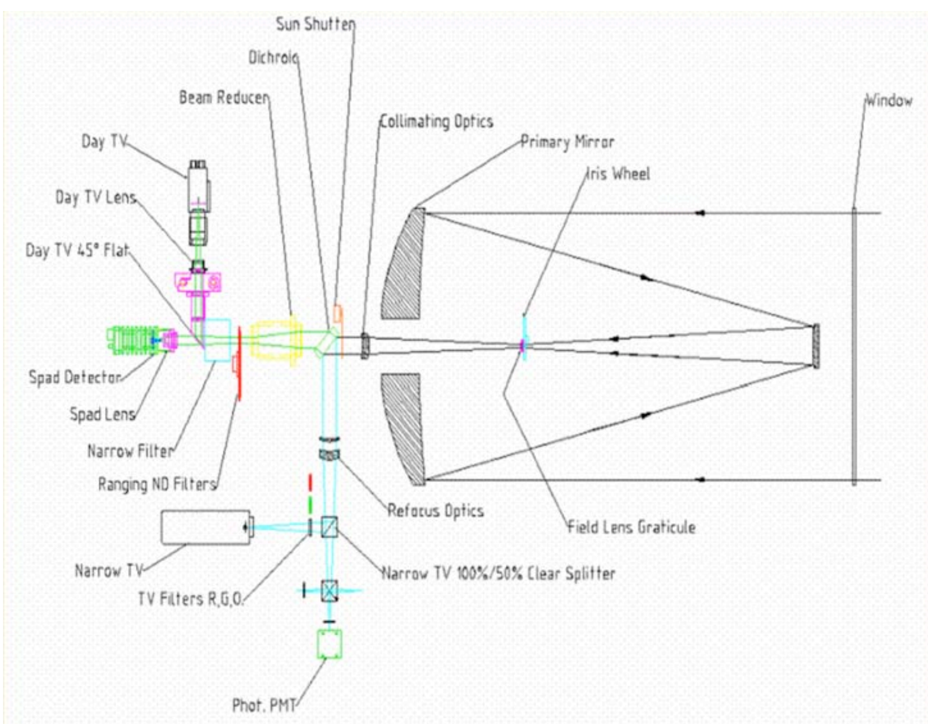

Figure 1. Optical layout of the SGF SLR system.

Returns are maintained statistically at single photon levels by automatically and rapidly determining the current true return rate throughout all calibration and satellite range operations and automatically varying the value of the neutral density filter that is placed in the optical receive path. The optical layout of the whole system is shown in Figure 1, where the neutral density wheel is seen in front of the narrow-band daylight filter.
Also seen is the narrow-field TV system for night time pointing assistance, a TV system for daytime imaging of laser backscatter and a photo-multiplier tube for high-speed photometry.
One of the problems that has been overcome for successful daytime ranging using narrow divergence, low energy laser systems is pointing error caused by heating-induced distortion of both transmit and receive optical mounting systems. The ‘day TV’ system shown schematically in Figure 1, in combination with a frame-grab processor, allows daytime visual monitoring of the backscattered image of the laser and of bright stars. These innovations are invaluable for fine adjustment of the directions of transmission and reception, and greatly aid daytime tracking.
Occasionally, after a manoeuvre, satellites can be difficult to acquire for laser tracking. The SGF telescope is equipped with a wide-field telescope and camera combination that is used to aid night time acquisition; a visual real-time display is provided (seen in Figure 2 picture below), along with digital frame-by-frame recording. Recently the system has been upgraded to enable detection of a field of view of nearly 2^o, very useful for recovery of objects as faint as 12^{th} magnitude.

Figure 2. Wide-field TV system, during laser ranging operations.

1.1. SLR system Upgrade.

The philosophy of the SGF laser ranging program has always been to maximise the stability of the data product. This aim has been achieved, as regularly evident in the ILRS quality report cards, by continually monitoring the accuracy of each element of the system. In particular, we have made many test measurements on the detectors and counters, the results of which have been widely published and are available on our

website. Results that directly impact on ranging accuracy are: (a) non-linearity of the Stanford counters used to measure time-of-flight and (b) time-walk within the C-SPAD when ranging to extended targets at high return levels. The solutions to these issues that are in place at present are to determine and remove the counter non-linearity effects using a series of comparisons between the Stanford counters and a high-precision event timer (Gibbs, *et al*, 2003) and to keep strictly to single photon return levels (Appleby, Gibbs, *et al*, 1999), at the expense of an inevitable increase in random noise. In addition, at single photon return levels, it is possible to compute very accurate corrections to refer the laser range measurements to the centres-of-mass of the primary spherical geodetic satellites (Otsubo and Appleby, 2003).
However, better solutions that are in the advanced planning stage are to build a high-accuracy (sub-mm) event timer based on picosecond-level Thales timing modules, and to purchase a 2kHz, short-pulse laser system, that will increase both data yield and single-shot precision. The event timer is currently being built in-house from the timing modules and the laser is due to be installed in summer 2005. Of course, to carry out high-repetition laser ranging, the event timer is an essential element to deal with the multiple pulses in train to the satellite and back throughout each pass. However, we have carried out link-budget calculations based on work by Degnan (1993), which suggest that even though the single-pulse energy of the new laser will be some fifty times less than that of the current Nd-YAG system (0.4mJ *cf* 20mJ), a reasonable number of returns should be detected even if the new laser is used at low repetition rate (10-13Hz). It is likely that the first stage of the upgrade will follow this route, with high-rate ranging awaiting full implementation of the event timer.

2. GNSS systems.

It is an ILRS requirement that Operational Stations be co-located with IGS receivers. In fact, the IGS site HERS has been operational at Herstmonceux for some fifteen years and the site HERT (relocated HERP system) has been operational since 2002. Besides producing hourly and daily RINEX GPS and GLONASS data, the HERT system also streams navigational data directly to the Internet in support of a EUREF realtime Pilot Project. Unfortunately, during the period 1999 April to 2001 May the HERS system was performing sub-optimally, with the result that it appeared to GPS analysts that the site had jumped some 14mm east. This resulted in both lack of confidence by the community in data from HERS and a second, erroneous, entry for HERS coordinates in ITRF2000. In order to detect early any further problems with either receiver, we have developed automatic GPS QC processes that may be of interest to the ILRS community. The first is a daily sky-coverage plot, taken from the previous day's RINEX files, and is designed as a check on antennae performance. The more detailed QC processes are based on full global and HERS-HERT differential GPS solutions, using the GAMIT processing software developed at MIT, USA. Baseline solutions between the two Herstmonceux systems, which are some 100m apart, are very good checks on the quality of their data, as well as being of interest in studies of site stability. Results from all these QC solutions are updated daily on the SGF website at http://nercslr.nmt.ac.uk .

3. Absolute Gravimetry.

Funding from the UK Natural Environment Research Council has been secured, in a joint proposal with the UK Proudman Oceanographic Laboratory (POL), for the purchase and installation at Herstmonceux of an FG5 Absolute Gravimeter, built by Micro-G Solutions, Inc. Key to Earth-system monitoring is maintenance of a terrestrial reference system with accuracy in global scale of 1 part per billion. In order to develop such a capability within the European and global community, an initiative to establish a European Combined Geodetic Network (ECGN, Ihde, Baker, *et al*, 2003) is underway within the auspices of EUREF, a European sub-commission of the International Association of Geodesy. One of the objectives of ECGN is to establish core sites where geometric positioning (GPS/GLONASS/SLR), physical height and gravity field components are all measured to sub-cm accuracy. Given its long record of precise space geodetic and ancillary measurements the SGF site at Herstmonceux has already been accepted as a 'station' within ECGN. Linked to the existing space geodetic techniques by precise site-ties, the absolute gravimeter will contribute absolute gravity measurements from this site of precisely known location within the international terrestrial reference frame. In addition, the site will be very valuable for side-by-side inter-comparison of the POL, and other, absolute gravimeters. This addition to the capability of the SGF site will make the SGF into one of the leaders worldwide, because of the range of different techniques that are now available. It will undoubtedly strengthen absolute gravimetry work within the UK.

Specifically, the absolute gravimeter observations will be used to determine the vertical crustal movements at Herstmonceux to better than 1 mm/year (Williams *et al*, 2001). The absolute gravimetry technique is completely independent of the space geodesy measurements and will therefore provide an important check on any systematic errors in those measurements or in their interpretation and in particular will provide information on global seasonal signals, as well as higher frequency local deformations from the seasonal to the tidal bands.

The gravimeter will be installed in the basement at Herstmonceux in autumn 2005.

4. Conclusion.

The Space Geodesy Facility is undergoing a major upgrade and expansion of capability. It will soon have KHz ranging capability and a very accurate epoch timing system. The inclusion of absolute gravimetry measurements on site will greatly add to the scientific value and scope of the Facility. These upgrades, however, will be carried out at no cost to the precision, accuracy or quantity of the laser ranging observations from the site, which have been made essentially un-interrupted since 1983.

5. References

Appleby, G.M., Gibbs, P. Sherwood, R.A. and Wood, R. Achieving and maintaining sub-cm accuracy for the Herstmonceux single-photon SLR Facility, *Laser Radar Ranging and Atmospheric Lidar Techniques II,* SPIE Vol 3865, 52-63, 1999.

Gibbs, P, Koidl, F and Kirchner, G. Range Comparison Results for Various EUROLAS SR Timers, in *Proc. 13th International Workshop on Laser Ranging*, Washington DC, 2003.

Otsubo, T. and Appleby, G.M. System-dependent center-of-mass correction for spherical geodetic satellites, *Journal of Geophysical Research*, Vol. 10, No. B4, 2003.

Ihde, J., Baker, T., Bruyninx, C., Francis, O., *et al*. Development of a European Combined Geodetic Network (ECGN), ECGN Working Group, IUGG General Assembly, Sapporo, Japan, 2003.

Williams, S., Baker, T. and Jeffries, G. Absolute Gravity Measurements at UK Tide Gauges, *Geophysical Research Letters*, Vol. 28, No. 12, June 15, 2001.

Degnan, J.J., Millimeter accuracy satellite laser ranging: a review, Contributions of Space Geodesy to Geodynamics: Technology, Geodynamics Series, D.E. Smith and D.L. Turcotte (Eds.), AGU Geodynamics Series, 25, pp. 133-162, 1993.