CCD and SLR Dual-Use of the Zimmerwald Tracking System

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Abstract

The Zimmerwald Laser and Astrometric Telescope (ZIMLAT) has been designed for both satellite laser ranging and optical tracking with CCD cameras, the latter mainly for orbit determination of space debris by means of astrometric positions. The paper describes the main characteristics of the control programs, both for CCD and SLR and their interaction during interleaved operation and it summarizes some experiences after several years of dual-use.

Introduction

The Zimmerwald observatory celebrated its 50 years anniversary in 2006. Its original purpose was an astronomical observatory for the University of Bern, Switzerland, mainly designed for sky surveillance (search for supernovae, minor planets and comets). However, it developed more and more into an observatory for space geodesy, starting with optical (photographic) tracking of satellites in the sixties, laser tracking since 1976, permanent GPS (and later GLONASS) tracking since 1991 and finally optical tracking again, mainly of space debris, using CCD cameras and digital image processing. In 1997 we replaced the former SLR tracking system (50 cm telescope, Nd:YAG laser) with a new 1-meter telescope and a two-wavelength Ti:Sapphire laser (846 nm and 423 nm wavelengths). The new ZIMLAT telescope has been designed for dual use, i.e. it serves as transmitting/receiving telescope for satellite laser ranging as well as a telescope for astrometric observations of space objects, mainly space debris.
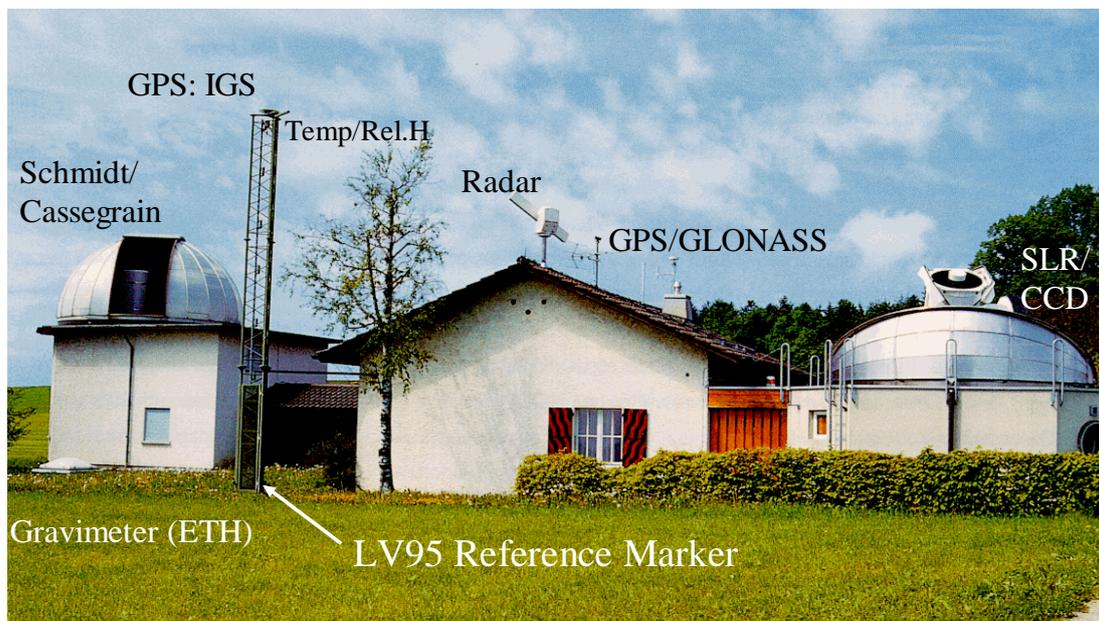

Figure 1: The Zimmerwald Observatory

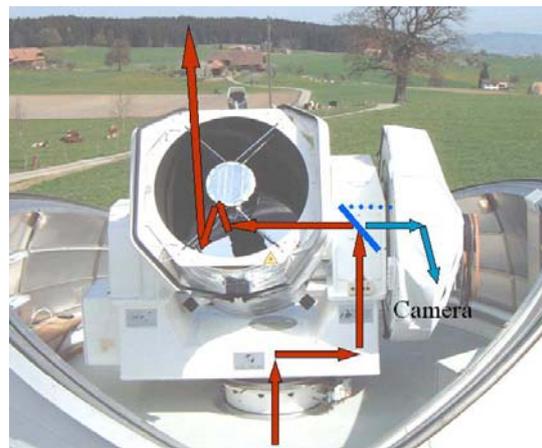**The Zimmerwald Laser and Astrometric Telescope ZIMLAT**

The main characteristics of the telescope are as follows:

The diameter of the main mirror is one meter. The telescope is of the Ritchey-Chretien type with main mirror, secondary mirror and a flat 45-degree tertiary mirror reflecting the image sideways into the elevation axis.

A vertical platform on one side of the telescope serves as mounting surface for four optical tables, with reduction optics, filter wheels and CCD cameras (Figure 2). The platform can be rotated around its horizontal axis (independent from the motion of the tube around the elevation axis) to derotate the image on the camera according to various strategies. The camera to be used for observation can be selected by means of a rotating mirror (with four distinct positions) in the center of the platform.
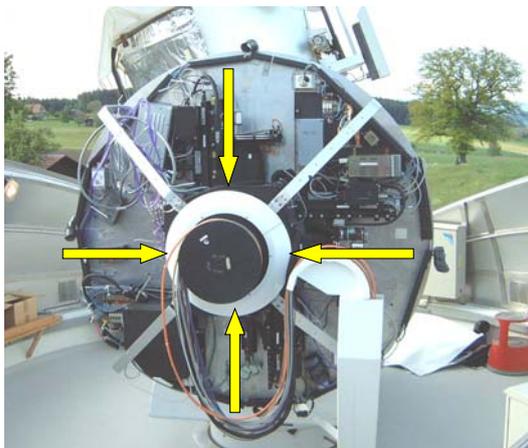

Figure 2: Instrument platform   *Figure 3: ZIMLAT telescope*

For Satellite Laser Ranging the laser beam is guided, slightly off-axis, through the Coudé path to the telescope (Figure 3). Its diameter of 1 cm at the exit of the transmit table is increased to 15 cm by the telescope optics. The receiving beam fills the full aperture of the telescope as well as the Coudé path back to the receiving table.
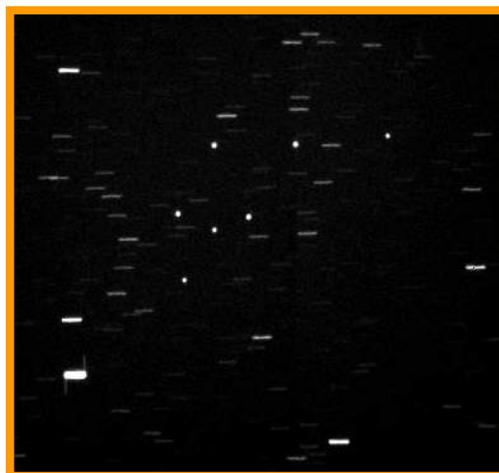
*Figure 4: 7 Geostationary Astra satellites (field of view 12x12')*

Figure 4 shows a sample image of one of the CCD cameras with 7 geostationary satellites within a field of view of about 12 arc minutes squared. The telescope was

kept fixed during the exposure time, showing the daily rotation of the Earth as short traces of the background stars.

The separation between the CCD and SLR observation modes is done by a fairly large dichroic 45-degree beam splitter mirror in the elevation axis of the telescope. It can be pneumatically removed (tilted) for high-precision CCD imaging. During night-time SLR tracking a video camera on one of the four camera ports can be used for visual verification of the tracking with the dichroic beam splitter inserted.

The Control Systems

The Satellite Laser Ranging part is controlled by the program *ZIMLAS* running on an Alpha workstation (operating system: VMS). It communicates with two specialized PCs for data collection and control of various electronic components and for the control of the telescope. The workstation handles the satellite predictions, generates the observation schedule (example in Figure 6), stores and post-processes the range observations, interacts with the operator in manual mode or controls the whole system in fully automated mode (see also Gurtner et al, 2002).
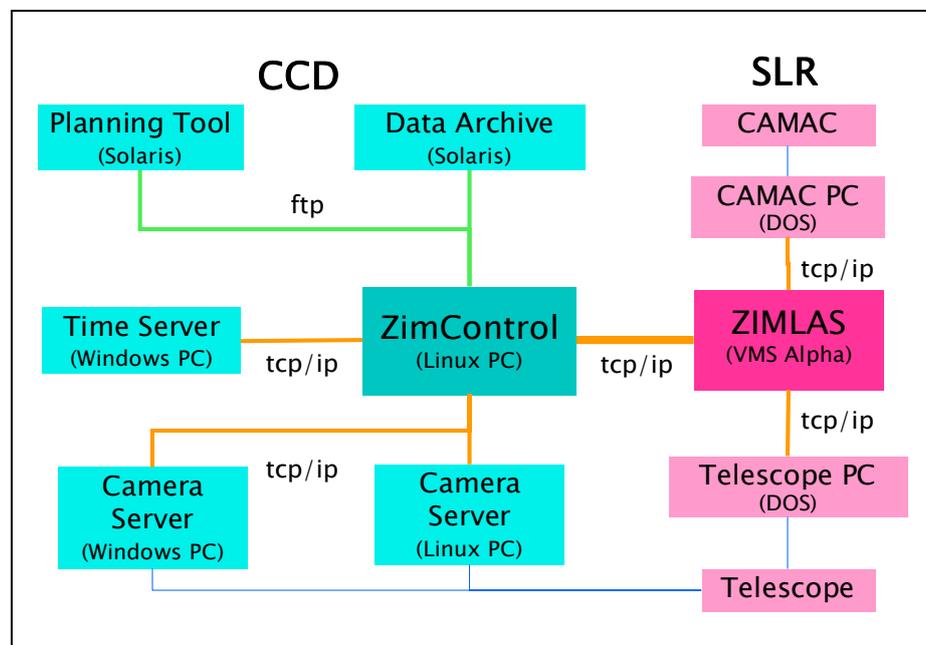
Figure 5: Control Systems

The control system for CCD observations (program *ZimControl*) is hosted by a Linux PC. It handles the observation schedule for CCD observations, interacts with the CCD cameras through specialized camera servers, and stores and pre-processes the digital images.

CCD Targets and Observation Plan

The following targets and objects are routinely tracked

- GEO (geostationary objects)
    - Active satellites
    - Space debris
- GTO (geostationary transfer orbit): Upper stages, debris
- Minor planets: Confirmation exposures for Near-Earth Objects

- GPS satellites to check system status (e.g., timing system)
- Photometry: Change of visual magnitude of objects due to their rotation
- Bias and dark current exposures (camera properties)
- Projection parameters, image distortions (telescope and camera properties)
- Focussing exposures (temperature- and elevation-dependent)

```
------------|-------------------------------------------------------------------
 # Satellite 14:42:44                        15:15:45                    15:47:45
------------|-------------------------------------------------------------------
01 CALIBRATE ======+###=================================+###=============
02 GPS-35    +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
03 GLONASS-89+++++++++++++++++++++++++++++++++++++####++++++++++++++++++++++++
05 LAGEOS-2  #######+++########++##++####+++----------------------------------
06 GPS-36    ---------------------------------------------------+++++++++++++++
07 ETALON-2  ---------------------------------------------------------------++++
08 LAGEOS    ----------------+##++##++++#########----#########++++###########+
------------|-------------------- 1 char =  60 seconds --------------------
```

Too close to sun

Figure 6: *Automatically generated observation schedule (SLR)*

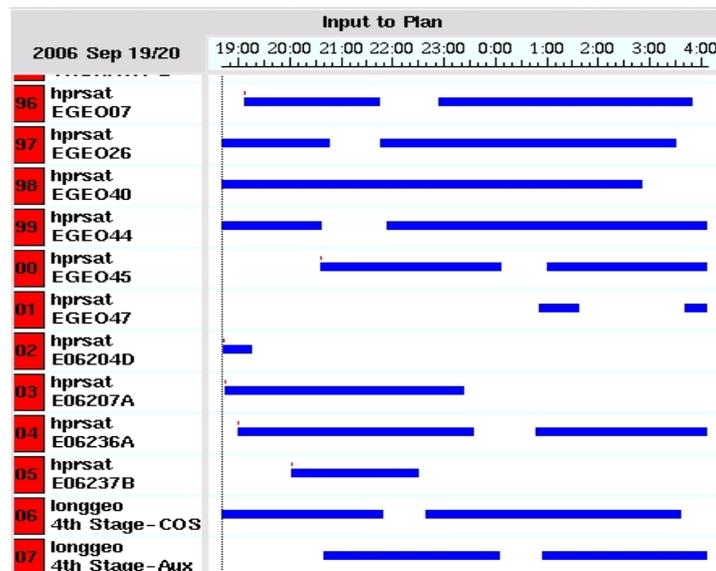Figure 7 shows an observation plan with targets and their possible observations periods during one night.

Figure 7: *CCD observation plan*

Insertion of CCD observations into SLR operations

Whenever the sun is more than 9 degrees below the horizon the CCD control system automatically checks if the SLR tracking system is currently operating.

If it is and if there are suitable objects in the observation plan the CCD system starts requesting observation time from the SLR system, starting with a time slot of 10 minutes, gradually reducing its length down to a minimum of 3 minutes if the request is not granted. This process is repeated over and over until a request is granted.

On the other side the SLR system checks each request, compares the requested duration with the current SLR tracking scheme and grants or rejects the request

according to the following conditions:

- Time since last CCD observation "large enough"
- Remaining pass segment of current SLR target "large enough"
- Already a minimum number of successful SLR observations collected
- Currently not in calibration mode
- CCD mode not blocked by operator

"Large enough" depends on the priority of the current SLR target and on the priority assigned to CCD operations.

If the request is granted the SLR system interrupts the current SLR tracking, puts the telescope into CCD mode (removal of the dichroic beam splitter from the elevation axis, pointing of the selection mirror on the platform to the requested CCD camera) and sends the requested object position or trajectory to the telescope control PC for tracking.

The CCD control system commands the camera to take an exposure and stores the digital image for further processing. Depending on the length of the granted observation interval several images of the same object or of different objects may be collected.

At the end of the current CCD observation interval the SLR system puts the telescope back into SLR mode and continues to range to the SLR targets according to the automatically updated tracking scenario.

The CCD control system then starts all over again with new requests for CCD tracking as long as the SLR system is in operation and until dawn.
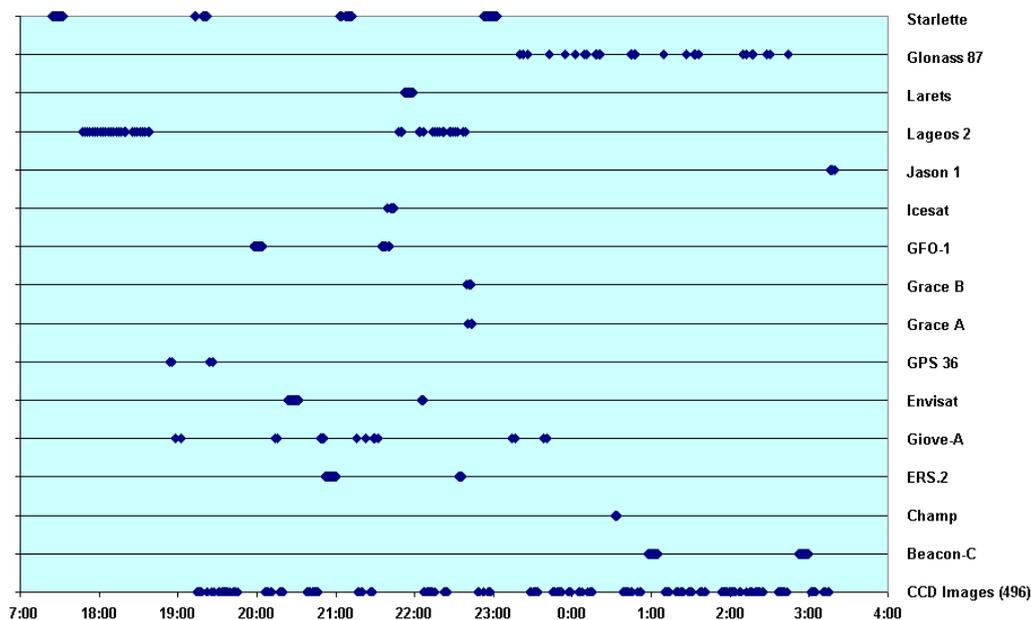
Figure 8: SLR/CCD interleaving

Switching between the two modes SLR and CCD needs all in all less than 30 seconds, repositioning of the telescope included. Figure 8 shows the actual tracking scenario (SLR satellites, CCD observations on the bottom line) of the night of September 1st, 2006. Thanks to the rapid interleaving of CCD into SLR, especially into the long passes of medium-high (Lageos 1,2) and high satellites (navigation satellites and Etalon 1,2) no substantial reduction of the SLR data output could be observed.

Figure 9 shows the monthly number of images collected during the last one and a half years.
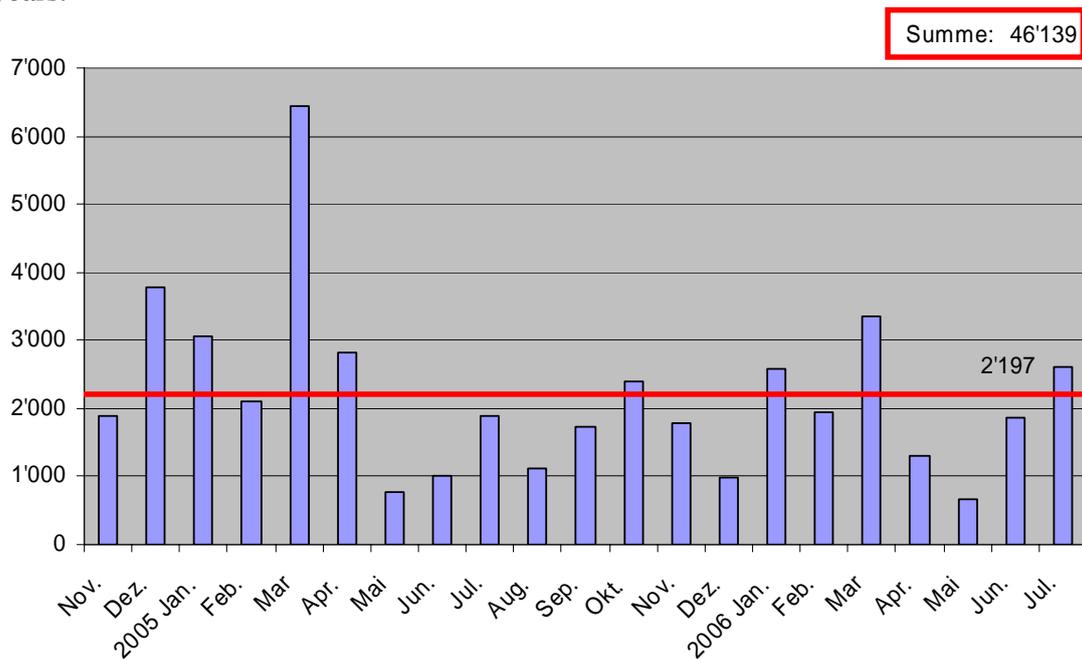
Figure 9: Monthly number of CCD images Nov 2004 - Jul 2006

Automation

The two control programs SLR and CCD are independent programs (running on two different computer systems). Either one or both can run completely automatically and unattended or under operator control.

In the extreme case (good and predictable weather conditions provided) several observation sessions of a few hours length each can be set up and submitted in advance by simple commands like

```
AUTO_SLR 20:00 22:00 WG MEDIUM
```

defining start and end time of the session, responsible observer's initials, and the priority assigned to CCD observations. All the rest is taken care of by the two control systems.

Post-processing

SLR data post-processing, i.e.,

- computation and application of an average calibration constant
- data screening
- normal point generation
- exchange format generation and submission of the data to the ILRS data center

can either be done interactively (daylight: mandatory) or fully automatically.

Image processing is automated and runs in the background on a Linux system at the university (the image files are automatically transferred to the university right after acquisition):

- Object recognition
- Reference star selection
- Determine image positions of stars and objects

- Astrometric position of objects
- Image archiving

The automatic processing of the previous night is checked interactively and problematic cases are reprocessed manually.

Conclusions

The dual use of the Zimmerwald Laser and Astrometric Telescope ZIMLAT has proven to be very cost-efficient. Although the telescope's design and operation is more complicated than the one of a single-mode instrument it provides us two different observation techniques for little more than the costs of a simple telescope. Thanks to the high degree of automation the two modes can be used nearly simultaneously without significant reduction of the SLR data output.

References

[1]   Gurtner W., E. Pop, J. Utzinger (2002), *Improvements in the Automation of the Zimmerwald SLR Station*, 13th International Workshop on Laser Ranging, October 7-11, 2002, Washington, D.C.