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Improvements in the Automation of the Zimmerwald SLR Station

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Abstract

The paper summarizes the components essential for automated or remotely controlled operation of the Zimmerwald Satellite Laser Ranging station and describes in more details new components and recently performed improvements.

1. Introduction

During the last two years automated and remotely controlled operation of the Zimmerwald Laser Station has mainly been used to extend the session lengths assigned to an operator, or to react to unpredicted (positive) changes in the weather conditions.

At the Deggendorf Laser Workshop in 1998 we already presented major components necessary for an automated and/or remotely controlled operation [Gurtner et al, 1999]. In the meantime we added additional features and we optimized already existing components to improve the performance of the station under these special conditions.

In this paper we try to address most of the topics proposed by the chair for the session „Automation and Control Systems".

2. Prediction Processing

Satellite orbit predictions in the form of position and velocity vectors given in an Earth-centered and Earth-fixed coordinate system related to a well-defined (simplified) force model (the so-called „tuned IRVs") are received, depending on the satellites, every few weeks, weekly, daily or even several times per day per E-mail via the ILRS mail prediction exploder ilrspred@irls.gsfc.nasa.gov.

All the necessary computations to generate station-dependent pass lists and tracking elements for the telescope are performed fully automatically:

- Extraction of the prediction mails from the mail box and insertion/replacement of the IRV sets in satellite-dependent prediction files (every few hours).
- Extraction of maneuver prediction files from the mail, scheduling a process to insert the post-maneuver elements into the prediction files at the time of the maneuver (every few hours)
- Generation of pass lists for the next two weeks (weekly)
- Generation of pass-specific ephemeris lists: Epoch, azimuth, elevation, range, derivatives, and Earth's shadow information, taking into account time bias information available at the time of computation (hourly for all passes starting after 60 to 120 minutes)
- Application of additional time bias tracking corrections according to the most recent time bias information downloaded from the time bias distribution server at aiuas3.unibe.ch:7840 (at start of tracking)

3. Sky Condition, Adverse Weather Detection

An ideal sky condition and adverse weather detection system should at least provide during day and nighttime real-time information about

- clear sky / clouds / haze for the whole hemisphere of the sky
- wind speed
- precipitation

in a computer-readable form (for automated operation) as well as in a way accessible for human inspection.

Currently we have the following systems available:

- Two external, roof-mounted color video cameras connected to a web server.
  → Remote inspection of the general weather conditions during daytime.
- A color video camera mounted on the telescope, connected to both a video screen at the operator console and a web server for remote access.
  → Visual inspection of the detailed sky conditions in the tracking direction during daytime (field of view some tens of degrees, adjustable by motorized zoom optics).
- A black and white high-sensitivity CCD camera mounted in the receiving path of the main telescope mirror connected to both a video screen at the operator console and a web server for remote access.
  → Visual inspection of the detailed sky conditions in the tracking direction (and of the prediction accuracy) during night time (field of view about half a degrees).
- Rain sensor, status accessible by the station computer and connected to a warning lamp.
  → Rain warning when dome is open, automatically closing the dome and stopping the tracking.

As there is currently no possibility to access the cloud coverage by the station computer we can launch automatic processing under human control only, and we do it only under reasonably safe weather conditions.

4. Remote Control, User Interfaces

The main user interfaces during tracking are realized as VT-220-type terminal windows and X-11 graphics windows:

- On the main station computer screen:
  - Simple VT-220 window for system and tracking program message display
  - Graphics window to display the observed ranges within the set range gate (different colors to distinguish between identified returns and noise, and between the blue and infrared wavelength)
  - Graphics window to display a sky plot of all selected satellite passes, the current pointing direction of the telescope, and the positions of the sun and the moon
  - Small text window with the real-time status of the EUROLAS stations (Figure 1)
- Main computer keyboard for any command and tracking system parameter input
- Separate fast VT monitor for the continuous display of relevant system parameters (Figure 2)
- Video monitor for the daylight (Figure 4) and the nighttime tracking cameras

Therefore it is easily possible to access the station control via Internet from a remote system with simple telnet sessions. In order to have the graphics information at disposal (which is not absolutely necessary for successful operation) the remote system must have an X-server software installed.

```
------------------------------------------------------------------------------
Graz          2002-08-13 14:17:32  Glonass87  LST     0  HON224  0.000
Potsdam       2002-08-13 14:18:01             OUT
Zimmerwald    2002-08-13 14:18:48  Glonass87  CUR     0  COD791  0.000
Wettzell      2002-08-13 14:18:41             OUT  (Tracking Idle)
Grasse_slr    2002-08-13 14:06:10  Lageos2    LST   653  NER022  0.002
Herstmonceux  2002-08-13 14:18:26             OUT
Ajaccio_ftlr  2002-08-13 13:59:00             OUT
------------------------------------------------------------------------------
```

Figure 1: EUROLAS status display

The contents of the fast VT monitor is displayed on the remote screen in a second VT-220 window (Figure 2). This screen and the command keyboard can also be duplicated on a remote system during normal (local) operation for debugging, educational or control purposes.

The images from the external (Figure 3) and the tracking cameras (Figures 4 and 5) are remotely accessible by any web browser.

```
+-------------------------------------------------------------------------------+
|  Satellite    :  LAGEOS-2                                Visibility : SUN     43|
+-------------------------------------------------------------------------------+
|  Initialize  :  Maximum   # of Shots :  40     Actual # of Shots :  36        |
|  OK             Necessary # of Hits  :   6     # of Init Cycles  :  12        |
|                                                                               |
|  Manual Corr.:  Step:  4" Up/Dn Lf/Rg:   0/  2 Total:   0/  2 E/A:   0/ -8    |
|  Search      :  Step:  4" Along/cross:   0/  0 Total:   0/  0            7 "  |
|                                                                               |
|  Obs.Interval:   0.1 s        ADC 1/2: 524   1 15.6 mJ  RT-Filter:      0 ns  |
|      Window  :    40 ns       Rgtcorr:       0 ns       Previous :     44 ns  |
|  Diverg/Blue :   300 1875    0Late by:  -0.004 s                              |
|                                                                               |
|  Calibration :  Each 70. obs  ADC 1/2: 728  42  0.2 mJ  Obs.Value:  53.97 ns  |
|                                                                               |
|  Statistics  :  Calibr:  191 21%  Bad:  607  0% Ovfl:  3449  Hits:   1243 12%|
|                                                                               |
|  Auto: ON       Mode: M  Obs.: ON                ATC: OK   RNG     0100000000|
|                                                                    0111100001|
|  A 184.6987  E 31.3302  D 180      MAN CORR      13-AUG-02 16:10:19.8   6:41  |
+-------------------------+--------------------------+--------------------------+
|  DAY_TV            ON   |  TILT_ENA          ON    | DETECTORS          ON    |
|  ML_DRIVE    -5999 OK   |  ND_FILTER     143 OK    |                          |
+-------------------------+--------------------------+--------------------------+
```

Figure 2: Real-time display of system parameters

The amount of graphics and camera information to be downloaded to the remote system depends on the capacity of the remote internet connection. On slow lines it might be necessary to completely exclude the use of the graphics windows and the real-time update of the camera images.

All system components including the power-up, shutdown, and a limited adjustment of components of the laser are computer-controlled and accessible from the remote site.

Figure 3: Remote Visual Instrument Control (day)

Figure 4: Remote Visual Tracking Control (day)

Authorized staff can also execute some limited system control by sending respective commands from their cellular phones using the Short Message System (SMS) features. Generated standard output may be sent back to the phone again as SMS message. Examples: Power-up of the Laser, get pass lists, get information about recently observed passes, get system status, start tracking in fully automated mode (see below), abort tracking.

Figure 5: Remote Visual Tracking Control (night)

5. Automated Control

The system can be operated completely unattended. There are two modes of automated operation:

- Temporarily automated operation: The satellite tracking is started under complete operator control. After optional manual adjustment of system parameters like exclusion of satellites, non-standard settings of range gate windows, manual tracking corrections (search of the satellite), etc. the observer can switch to automated operation, either for a limited time period only or till the end of the selected tracking session. Even under automated operation the observer can manually intervene as usual.

- Fully automated operation: With the command

  ```
  AUTO_SLR  `power_up_time` `tracking_start` `tracking_end` `oper_name`
  ```

  the system is powered up (Laser on, initialization of the telescope) and the tracking started and stopped at the requested times using standard settings of the system parameters (all satellites in view).

  The procedure is started as batch program in the background, and it does not use any computer terminal as user interface during execution. However, using the remote control feature described above, temporary control of the tracking procedure can be gained from any remote (or, for that matter, also local, i.e., on-site) system.

6. Automated Session Planning

All the satellites on the ILRS tracking list are assigned simplified priority numbers (1 to 8) and system parameters (e.g., minimum tracking interval for interleaved tracking).

All possible (or, during manual operation, all selected) passes within the selected tracking session (duration of up to six hours) are checked for sun interference, maximum elevation excess, and minimum pass length. If more than one satellite is visible the respective passes or pass segments are split into small parts, according to their tracking priorities and minimum tracking intervals. The resulting tracking scenario is displayed to the operator or automatically processed under automated tracking. The operator can overwrite this scenario anytime, i.e. exclude or re-include satellites, change from one satellite to another or re-invoke the generated scenario.

Figure 6 shows an example with an interference between GFO-1 and the sun of about 90 seconds length during which the system proposes Lageos-2 to track.

```
-------------|--------------------------------------------------------------
 # Satellite 12:18:39                                               12:48:04
-------------|--------------------------------------------------------------
01 GLONASS-87############+++++++++++++++++++++++++++++++++++++++++++++++++++
02 GRACE-A   ------------##++##---------------------------------------------
03 GRACE-B   ------------++##++---------------------------------------------
04 LAGEOS-2  ------------------####+++####+++++++###########################
05 GFO-1     ----------------------###+---#######+--------------------------
-------------|---------------------- 1 char =  30 seconds ------------------
```

Figure 6: Proposed Tracking Scenario

7. Real-Time Noise Filtering and Tracking Improvement

As already described in [Gurtner et al, 1999] acquisition of the satellite is done as follows:

- Initialization phase: Initial identification of true returns among the collected times of flight by
  - directly inspecting the differences between observed and predicted values
  - converting all times of flight into respective along track errors (time biases) and inspecting these values.

  using an initial range gate window according to the expected prediction accuracy (few hundred nanoseconds)
  - automatically or manually searching (spiraling) around the predicted satellite position

- After successful initialization:
  - Use improved predictions to separate new true returns from noise
  - Use identified returns to improve the computed time bias
  - Continuously improve the satellite predictions by applying the computed time bias
  - Center the range gate window around the improved predicted ranges, reduce the window to smallest value (currently: 40 ns)

- Automatically and continuously change telescope pointing by small amounts in all four directions to find and keep maximum return rate. (The return rate is independently kept below 30 percents by adjusting either the transmit beam energy or changing the position of a variable neutral density filter in the receiving path).
- If during a certain time no good returns could be identified: Switch to initialization mode.

8. Aircraft Detection

As described in [Gurtner et al., 1999] we get the air traffic control radar positions of the airplanes in the area around Zimmerwald in real-time. The station computer continuously compares the extrapolated positions of the airplanes with the direction of the laser beam. In case of possible conflicts the computer prevents the laser from generating pulses.

A small radar driven in parallel with the telescope detects small and low airplanes, balloons, etc. not included in the ATC data stream.

9. Security and Safety Issues

The following measures are taken:

- Sun protection:
  - The station computer excludes portions of the passes approaching the sun to more than 25 degrees.
  - The telescope computer avoids the sun when positioning or changing satellite tracks by at least 20 degrees
  - A sun detector is mounted on the telescope in the pointing direction with a field of view of about 20 degrees. In case of problems the protective cover on the front of the tube is closed automatically by hardwired connections
- Rain protection: In case of rain and open dome a flash light warns the staff in the control room. Under remote or automated control the dome is immediately closed or not opened at all.
- Laser hazard:
  - During power up a flash light warns the staff in the control room
  - Under remote or automated operation a motion detector in the dome may interrupt the Laser pulse generation
- General:
  - A flash light in the control room is switched on during remote or fully automated operation
  - The external access point to the roof around the dome is labeled with warning signs.

10. Automated Data Post-Processing and Submission

Currently the data are post-processed under operator control as soon as possible (basically within minutes) after each pass (can be done simultaneously with the tracking of other satellites).

The operator just selects the pass(es) to process. The post-processing (applying the average calibration values, off-line noise filtering, normal point and quick look message generation) is done automatically.

Daytime pass residuals are displayed graphically, the operator has to visually inspect them and interact manually (exclude/restore observations, reprocessing), if necessary.

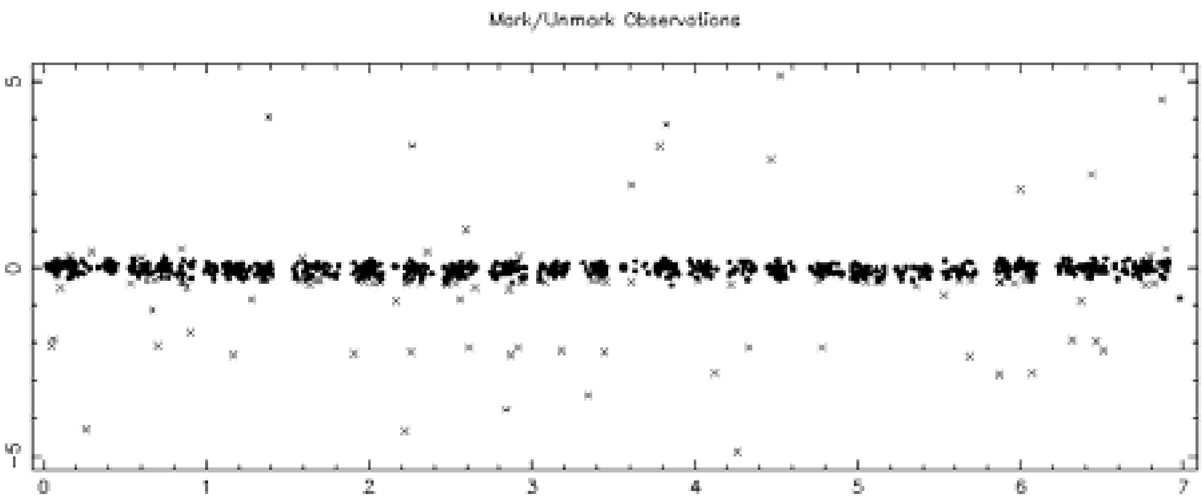

Figure 7: Interactive Data Screening

The system proposes the operator to submit or retain the pass, depending on the calibration rms and post-processed pass rms. Passes flagged for submission are then automatically send to the European Data Center at DGFI, Munich by E-mail.

11. Current Experiences

11.1 Remote Control

Under remote control the operator has nearly all the system options and information available. Therefore the remotely controlled operation is nearly as successful as the onsite operation.

Limitations:

- Some Laser adjustments can only be done on site. In times when the Laser needs frequent adjustment, extended sessions under remote control are not recommended.
- Some rare crashes need operator intervention, e.g., if the instrument runs, due to whatever reasons, into the limit switches.

- Partly clouded sky of course is more difficult to deal with from a remote site as there is no cloud mapper available.
- The psychological element cannot be completely discarded: A certain reservation against a completely unmanned station operation is understandable.

We use the remote control mainly

- in case of surprising weather changes
- to bridge gaps between assigned sessions
- for maintenance and operator support

11.2 Automated Operation

At night time under reasonable weather conditions we experience a good performance under fully automated operation. During the day it is more difficult to keep the instrument optimized on track, especially if there weak returns only.

The same limitations are valid as we have under remote control. In addition:

- Clouds are even more disturbing because the system does not readily know why no returns can be identified: So the tracking scenario cannot be adjusted to the actual weather conditions. A cloud detector/mapper would significantly help here.
- Unpredicted weather changes. Although we have a rain sensor attached to the system, a certain risk against damages by rain fall cannot be excluded.

We use the automated operation mainly to cover short breaks (lunch, naps, …) and to bridge gaps between sessions (up to three hours maximum, under clear-cut weather conditions only).

References

Gurtner W., E. Pop, J. Utzinger (1999). „Automation and Remote Control of the Zimmerwald SLR Station". Proceedings of the 11th International Workshop on Laser Ranging, Deggendorf, September 20-25, 1998. Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 11, Fankfurt am Main, 1999.