Trials and limits of automation: Experiences from the Zimmerwald well characterized and fully automated SLR–system

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Hardware Communication Layout

- Simple' replaceable (hard-/software)
- Old but well-defined fixed APIs
- Graphical or unknown UI
- or OS dependency
- or non-general-purpose H/S
- or very bad connection/...

Day and night
Automated Devices

- ~165 Devices
  - Moving Devices: Matching Lens, Divergence Optics
  - On/Off Devices: Laser Shutter, Tube Fan
  - Read-only Devices: Humidity Sensor, Maser In Voltages

- Design Rules:
  - MTBF: long lifetime,
  - less maintenance
Example: Some Devices...

- Piezo: electrical tild mirror
- Lens1
- Divergence Optics
- Lens2
- Beam Alignment Screens
- Control Unit
- CM_Shutter

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Software Maintenance

- **Linux is your friend here**
- **Philosophies**
  - Upgrading old, in order to maintain automation
  - Writing new, which automates new things, e.g. Envisat data processing
- ~300,000 lines Fortran77 source code, under revision control, some «minor» not
- **Design Rules:**
  - Less maintenance, use (**IX) standard interfaces
  - Simple expansible
- **BTW:** Use host- and usernames carefully...

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Remote Screen in xterm

Using terminal emulator:
Remote Screen in Smartphone

Not yet displayed correctly (interferes with virtual kbd), but kbd input works really!
Software Porting

Motivation:
- Old code has less bugs!
- Development very bad under DOS

Software interfaces:
- Text terminal/keyboard-based,
- TCP/IP network, only one X11 application (pgplot) for residuals,
- Byte code protocols (e.g. Modbus) network

Hardware interfaces:
- EPP, ISA
- Video graphics: If uses only text: API adapted to use ncurses calls
PC Hardware Maintenance and Porting

Idea: hardware redundancy, no complete new system, replace single components only

PCs Maintenance (copying):
- Station Control: made a virtual machine
- DAQ: almost cloned, lacks a print card
- Telescope: cloned
- Laser: program copied onto new PC and OS (Windows)

Porting DOS to Linux
- ISA port/memory mapped access seem to work: first time as user root, or Linux driver
- last interesting tests in real environment come up... difficult: timing restrictions if any

Btw: Mixed experiences with new (all-in-one) SPS
Limits of Automation

- **frequent**
  - optics cleaning
  - replacing: fans, power supplies, batteries

- **rare**
  - receive path: Fabry– Pérot adjustment
  - Maser frequency drift correction
Night Tracking Camera

- Like in the earlier days of SLR: Point to HEO sat., between laser pulses take a photo, evaluate photo: find HEO sat., calculate deviation, move telescope directly to sat. position
- Digital Camera Neo sCMOS (Andor) evaluated: should fit purpose
- Exposure Timing works
- Light shade pipe required
- Laser light filtering: Additional filter for IR too seems to solve
- Implementing Software of image processing continues...
- Analogue technique was so easy...
Safety of Low Energy Tracking

... should be fully automated and should be fully secure

- Targets: ISS (ELT: 0.1mJ), Sentinel–3A, ...

- for standard tracking: Why do we need so much energy at all? RegenOut 0.4mJ@532nm and 100Hz enough for all LEOs incl. Lageos (see also other publications...)

- currently, everything depends on the satellite name only
  - one software problem should not affect safety!:
  - second software variable from second data channel required? (like Go/NoGo–Flag)

- Energy measurement in real-time: Ulbricht Sphere + Photo Diode: less precision compared to thermal sensor: to be checked again

- divergence control seems to be reliable measurements continue when at 8mJ again
Excursion: Frequency Stability for ELT

- SLR Zimmerwald is phase locked to the Maser since 9.8.2016, 15:20 UTC
- Maser frequency drift is corrected manually: 1PPS Difference of GPS to the Maser is at the measurement precision of the GPS-receiver (res30ns/acc165ns)
- METAS (Time and Frequency Lab, located 8 km from station) checks for optical link between its Caesium fountain and station
Safety for European Laser Time Transfer (ELT)

Paper: “..ELT and Laser Safety for the ISS”, U. Schreiber et al., 2013

Some checks for our system specific implementation:

- **Easy to program:** For ISS, switch CM_SHUTTER (located after energy measurement) ON (to open) if laser energy is less than...

- **Mains Power Off/On Scenario and UPS (to be checked again):**
  - Control–PCs have UPS, **UPS can work contrary to safety**
  - laser power supply and chiller have no UPS,
  - Shutters should be closed by gravity (currently by springs)

- **Micro switches at Divergence Optics:** seems to be a good idea

- **Amplifier gain reduction:**
  - Delay between Amp pumping and laser pulse + polarizer attenuator might work
  - Switching off Post–Amps: Amps not at thermal operating point: For fully automated operation, have to be back in stable operation condition after ISS passage: **switching off Amps might be a bad idea**
New Systems

Idea: New technology: Carbon–Fibre–Tube: high stiffness, cheaper

- Used for Space Debris, not yet for SLR, ok, equatorial mount is bad for SLR …
- other motion controller: completely new, first version software, some minor source code imported from old system
- Camera readout “PCs”: low power SBCs at telescope axis: Cubietruck, no mechanics (less maintenance): no active cooling/fan, flash/SSD memory, a lot of similar boards available: to be evaluated

- Satellite pointing at arc sec precision, development affected already others
- For SLR some is missing: e.g. Sun avoidance and timing precision!
Conclusion

- Think carefully about what you’re going to implement, for both hardware and software!
- A lot of work to do...

Thank you very much for your attention!
Two new Towers for new Telescopes

Tower1

Tower2
ZIMLAT–Telescope used for
- Geodesy (SLR) and
- Imaging (Space Debris)
- Hybrid design is difficult: optical compromise

ELT: Event–Timing: Dassault–Elements required?
We don’t want to buy such expensive devices...
Time Transfer Principle

good clock at ISS

optical links only

SLR station A

A-B Time Comparison at pico second level

Time Lab A

Time Lab B

SLR station B
Time–Transfer Principle (2)

- **Purpose:** Clock comparison by Time-tagging on space and ground
- **SLR in parallel**
- **Satellite site cannot be changed easily**

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**On-Board Clock**

**Active Satellite**

**Timetags via RF-Downlink**

**Data-Server**

**Timetag-Correlation**

**SLR-Observatory**

**PD**

**Start**

**Eventtimer**

**Timetags**
Excursion: The used Clock in Space

- **ACES (Atomic Clock Ensemble in Space)**
  - cold atoms in microgravity
  - Combination of cold Caesium clock and H-Maser:
    - test of PHARAO frequency stability $10^{-13}\tau^{-1/2}$ and accuracy $3\times10^{-16}$
    - test of SHM frequency stability $2.1\times10^{-15}$ @ 1000 s

- **Applications in Fundamental Physics**
  - gravitational red-shift
  - drift in fine structure constant
  - anisotropy of light

Pharao prototype in CNES ZeroG Airbus (May 1997)
Time Transfer Predecessors: simple clocks

- **T2L2**: Operated by France, OCA and CNES
  - On-board Clock (USO) no longer State-of-the-Art
  - At end of lifetime
  - Since years precision evaluation: Allan–Variance: about 1 ps: optical transfer much better than RF ones
    Ground to Space section: 1 Triple data files tar-ball/ 1 day)
  - A lot of published papers

- **LRO**: Lunar Reconnaissance Orbiter (NASA), spacecraft around the moon (mission ended)
  - Requires enough energy, good weather conditions and schedule
  - Precision data NASA proprietary?
ELT: European Laser Time Transfer uses ACES

- **ELT difficulties:**
  - Operated by ESA via NASA via ISS–operators,
  - ACES launch scheduled for 2016,
  - Not yet operating,
  - ISS operated –2020?

- **Successor project of T2L2, in principal similar, new:**
  - improved detector–retro–package, ready for launch, pre–flight experiments and papers well–known
  - The best On–board Clock ever: ACES
  - ESA requirement: Ground–Data–Infrastructure ready before Hardware launch

- **SLR–Stations**
  - locked to Maser: Time comparisons can be made
ELT objectives (a copy from an ELT workshop..)

- **Clock Comparisons and Time Transfer**
  - Space-to-ground comparisons of clocks reaching a TDEV of 4 ps between 300 s and $10^4$ s of integration time, better than 7 ps on the long-term
  - common view comparisons below 6 ps per ISS pass
  - Non-common view comparisons below 6 ps after 2000 s of dead time
  - Space-to-ground and ground-to-ground synchronization of clocks

- **Laser Ranging**
  - Laser ranging performance at the centimetre level per single shot (50 ps one-way)
  - Comparison of ranging techniques: one-way optical ranging, two-way optical ranging, microwave ranging
  - Analysis of atmosphere propagation delays