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Automation and Remote Control of the Zimmerwald SLR Station

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Abstract

The paper describes those parts of the control system of the Zimmerwald SLR station needed to allow a (nearly) automated operation and/or a remote control of all major components by the operator or, currently for diagnostics and tutorial purposes only, from remote terminals. It discusses inter-process and inter-system communication, server program concepts, automated satellite acquisition, use of real-time air traffic control data, control of various components (like laser, dome, environmental sensors, optical parts, safety switches), possible conflicts between manual and computerized control.

1. Introduction

In 1995 the old Zimmerwald satellite laser ranging system was removed after about 10 years of routine operation and replaced by a new telescope and a new laser. Part of the old electronic control system (e.g., most of the CAMAC interface modules) and the station control computer could be saved for the new SLR system. A description can be found in [1].

The routine operation of the Laser Ranging System will again be mainly performed by staff (engineers of the Federal Office of Topography, students) the main jobs of which are centered around other activities. In recognition of this pronounced part-time involvement we tried (and are still trying) to automate the operation as much as possible, and we also introduced the means to be able to control the system from other places such as the university or even from home, not for routine operation but for trouble shooting and education.

This paper describes the main components of the system control relevant for automation, focuses on interprocess communication by tcp/ip and discusses the principles used for the remote control.

2. Computer Control

Figure 1 shows a detailed diagram of the computer control of the whole system. It is hierarchically structured with the VAX Station computer on top, three PCs (Telescope, CAMAC system, CCD camera) and a terminal server for serial input/output on the second level, microcomputers, PC and CAMAC interfaces on the third level and simple digital or analog input/output modules under control of the microcomputers on the fourth level.

The console of the VAXstation main computer is the only command and data entry/retrieval system for the operator. All interactions by the operator are either processed by the VAXstation or passed to one of the lower-level processors for execution. All routine system status displays also are handled by the VAXstation. All power on/off settings and most of the analog or digital settings and readings can be commanded by the operator through the top-level VAXstation.

All the control and computational programs running on the VAXstation and the three PCs are written in Fortran, with a very few low-level assembler or C language subroutines or libraries on the PCs.

The top two levels are connected through the local area network (Ethernet).

```
   + -- Main Computer - + --  Modem -- + -- Air Traffic Control
   |     (VAXstation)
   |
   + -- Telescope PC -- + -- PMAC (telescope motor amplifiers,
   |                    |             angle encoders)
   |                    |
   |                    + -- Time card (Gorgy <-- DCF77)
   |                    |
   |                    + -- Serial -- + -- Data Display
   |                    |
   |                    + -- Serial -- + -- MicroDAC 1
   |                          Bus      |     - Power on/off/status
   |                                   |         Beam Splitter
   |                                   |         Sun Cover
   |                                   |         Cameras
   |                                   |         Alignment mirror
   |                                   |     - Analog in/out
   |                                   |         Temp sensors
   |                                   |
   |                                   + -- MicroDAC 2
   |                                   |     - Analog in/out
   |                                   |         Camera ports (focus)
   |                                   |         Filter wheels
   |                                   |
   |                                   + -- MicroDAC 3
   |                                         - Analog in/out
   |                                             Matching lense (Coud, path)
   |                                             Deflection mirror
   |                                             (selection of camera port)
   |
   + --   CAMAC PC   -- + -- CAMAC Controller
   |                    |       Stanford counters
 E |                    |       Event timer (start pulse, CCD "shutters")
   |                    |       Gate generators
 T |                    |       Fast status bits
   |                    |       Fast command signals
 H |                    |         Receiver shutters
   |                    |         Calibration shutter
 E |                    |         Calibration filter
   |                    |         Pin hole (field of view)
 R |                    |         Rotating shutter
   |                    |         Beam splitter (0/50/100)
 N |                    |       D/A Converters
```

```
  |                    |        Laser attenuators (blue and IR)
E |                    |
  |                    + -- Lab PC card
T |                    |      Joy stick position
  |                    |      Beam divergence
  |                    |
  |                    + -- Time card (IRIG B <-- GPS)
  |
  + --   Terminal   -- + -- Serial -- + -- MicroDAC 1
  |       Server       |      Bus     |      - Power on/off/status
  |                    |              |          CAMAC Crate
  |                    |              |          CAMAC PC
  |                    |              |          Telescope PC
  |                    |              |          Counters
  |                    |              |          Detectors
  |                    |              |          Radar
  |                    |              |          Dome open/close
  |                    |              |          Dome light
  |                    |              |          Rain sensor
  |                    |              |          UPS monitor
  |                    |              |      - Analog in/out
  |                    |              |          Ambient temp/humid
  |                    |              |          Dome ventilator
  |                    |              |
  |                    |              + -- MicroDAC 2
  |                    |              |      - Power on/off/status
  |                    |              |          CCD Camera PC
  |                    |              |          ...
  |                    |              |
  |                    |              + -- MicroDAC 3
  |                    |                     - Power on/off/status
  |                    |                         Laser Components
  |                    |                         (Power supplies, shutters)
  |                    |                     - Analog in/out
  |                    |                         Laser Components
  |                    |
  |                    + --  Radar (positions)
  |                    |
  |                    + --  Barometer
  |                    |
  |                    + --  Data Display
  |
  + --  CCD Camera  -- + -- Fibre  -- + -- CDD Camera
  |   Controller (PC)     Optics
  |
  |
  + -- Second VAXStation  (offline/timed computations, backup, programming)
```

Figure 1: Computer Control

3. Conflicts between manual and computer control

Many components of the system can be controlled either manually (push buttons, switches, knobs, etc) or via input/output interfaces by the computer (either under program or operator control).

Examples:

- Beam divergence
- Power switches for CAMAC or telescope PC
- Laser shutter
- Laser attenuator
- Dome open/close
- Backscatter shutter

Depending on the operational requirements (ease of use, safety considerations, priorities, default positions or values) various solutions are possible:

a) Priority of the computer control:

Highest priority for routine operation. Computer control overrides manual settings. Not suited for devices that may endanger the safety of the maintenance staff or of equipment (e.g., laser shutter, attenuator, receiver (sensor) safety shutter).

Two versions have been realized:

1. The computer can disallow any manual interaction. The programs have to make sure that manual control is enabled again at program exit (even under abnormal termination)
2. The manual settings can change the computer settings until the next device command of the computer (operator, program)

b) Priority of the manual control:

The maintenance staff is sure that an operator or computer progam cannot interfere with the manual settings. Disadvantage: Wrong settings for routine operation requires manual intervention by the operator (training, check lists necessary). The computer should be able to at least read the current settings and warn the operator about wrong settings.

c) No special priority

Each setting can be performed by the computer and by manual interaction, as well, the later setting overrides the previous one. This option is easy to realize. However, conflicting situations are possible.

4. Interprocess Communication

4.1 Requirements

The communication (data and command exchange) between the programs / processes running on the VAXstation and on the PCs has to be performed across different platforms (VAXstation, PCs) running under different operating systems (VAXstation: VMS; PC: DOS [telescope, CAMAC], LINUX [CCD camera controller], later maybe workstations under UNIX) and in the future written in different languages (C in addition to Fortran).

The requirements for the transfer are not very demanding for a local communication:

- We need a very few hundred bytes per basic cycle which is 1/10 second, corresponding to the repetition rate of the laser.
- The transfer should be either pretty fast (e.g., within a few milliseconds) or asynchronous to avoid significant dead times during the actual transmission

4.2 Client / Server Principle

The communication between the programs is organized in a client/server mode:

- one of two communicating programs acts as a client, i.e., it requests information or sends commands or data and waits for the requested information or at least for an acknowledgement
- the other program acts as a server, i.e., it waits for and answers requests for data or executes actions according to the commands received, and sends an acknowledgement.

The following principles are used:

- The two programs keep their role as client or server for a certain communication link.
- There is no transmission from the server without the client's request
- The programs run on a fixed cycle of 0.1 second
- The PC server programs (CAMAC PC, telescope PC) synchronize themselves by timing cards
- The VAXstation client program synchronizes by means of one of the communication cycle: It waits for the acknowledgements/data of the CAMAC PC

4.3 Communication through TCP/IP

By making use of existing basic subroutine libraries (the so-called *socket* libraries) available on most platforms where TCP/IP is installed a direct communication between user-written programs running on these platforms can be realized rather easily.

This communication type can make use of the existing local area network (e.g. ethernet) used for Internet connections, so no new installations or hardware is necessary if the computers are connected to the network anyway.

TCP/IP-based communication is pretty safe, i.e., as long as the communication link is active, we have no problems with lost data packages or scrambled data.

Non-blocking receive is possible, i.e., data can be received asynchronously, without pausing the execution of the receiving program until the expected data has arrived.

At least on the local network level the transmission is very fast, the buffering is done by the low-level routines provided in the subroutine libraries.

Similar basic functions are available on all major platforms:

- *Connect* to a server
- *Accept* a connection request from a client, open the link
- *Send* a string of bytes
- *Receive* a string of bytes
- *Close* an open connection

To establish a connection from a client to a server the following steps have to be performed:

- Get the internet *address* of the server system
- Get the *port* number where the server program *listens* to calling clients
- Initialize connection by means of basic routines (create a *socket*, *connect* to remote *port*)
- On the server side: Create a *socket*, start *listening*, *accept* request from client

A string of bytes sent by one *send* command may arrive at the server in several portions. Therefore it might be necessary to include special end-of-string characters or the total length of the string to help detect the proper reception of the full string. To be able to eliminate preceeding junk characters start-of-string characters my also be appropriate.

4.4 Communication Format

We have defined for our communications a special format containing different types of commands, status requests and status messages or a mere acknowledgement.

Record Format:

```
$SOR,llll,nn,$msgid, ... ,$EOM,$EOR
             \__________________/
                 nn  messages
```

`$SOR`	Start of record
`llll`	Total length of record in bytes
`nn`	Number of commands or answers (=messages) in the record (00: “Empty record”, acknowledgement)
`$msgid`	Command or answer identifier
`$EOM`	End of command or answer
`$EOR`	End of record

All messages consist of ASCII characters (32-126) only.

Examples of messages:

`$SATRK,mmm,on,$EOM` (Start satellite tracking)

`mmm`	Total length of message in bytes (018)
`on`	Orbit number

`$PMOTD,mmm,dv,pi,pppppp,$EOM` (Drive Motorized Device to Position)

`mmm`	Total length of message in bytes (028)	
`dv`	Device number	
`pi`	Position identifier	01 : absolute 02 : relative
`pppppp`	Position	-99999 ... +99999

5. Components Important for Automation

The following chapter discusses a few components which are important if not necessary for an automated system:

5.1 Aircraft Detection

As our laser system exceeds the limit of energy for eye safety up to several tens of kilometers we have to ensure that no airplanes are hit by the laser beam.

As a first step we purchased a small commercial radar (Swissradar) mostly used for smaller boats or ships, added a two-axis mount, modified the electronics to allow for automated shutdown of the laser (fast shutter) within milliseconds after aircraft detection and wrote the necessary software to drive the radar parallel to the telescope. The radar beam has a width of about 2 degrees in the vertical and 20 degrees in the horizontal direction. The radar can detect small aircraft up to a range of about 10 km. This is enough to avoid problems with recreational aircraft and helicopters operating under visual flight rules.

With a minimum elevation of 20 degrees all airplanes interfering with the laser beam at a larger distance than 10 km are on an altitude of at least 3.5 km above the laser station and as such controlled by the Swiss air traffic control. We have been lucky to get the permission to access the continuously flowing and near-realtime data stream of the ATC containing the current positions of the airplanes within a radius of about 50 km around our station. A server program on the VAXstation computer continuously keeps track of the positions of the airplanes and compares them with the direction of the laser beam in three dimesions. If the latter comes too close to an airplane the main control program on the computer automatically blocks the laser using the same fast shutter as the onsite radar.

5.2 Satellite Acquisition

One of the major problems for automation is the reliable acquisition of the satellites, namely

- to account for misalignments of the telescope and for errors in the satellite predictions
- to detect the actual returns among a high number of noise especially during daytime tracking

5.2.1 Tracking Improvements

In addition to star calibration or calibration using actually tracked Lageos (or other high-quality satellite) passes of the mount model and the use of the time bias file distributed daily by RGO we have prepared the following functions:

- Search algorithm invoked after a certain amount of time without identified returns, (spiral search around predicted precision)
- Range gate is shifted during initialisation phase (i.e., when no true returns have been identified yet) according to the along track (delta t) component of the search correction

- After initialization: Maintain along- and cross-track components of the tracking correction during the pass

5.2.2 Signal Detection

If the satellite predictions are very precise the differences between observed and predicted ranges vary slowly with time, i.e. a majority voting of the counter readings can extract the true returns from noise. The resulting offsets between prediction and observation can be extrapolated and used for noise separation of future returns.

In case of poor predictions (especially for all low orbiting satellites) the differences between observed and predicted ranges vary rapidly with time, so they cannot easily be used for identification of the true returns. Under the assumption, however, that the largest component of the prediction error is along track (i.e. a delta time error) each return (i.e. counter reading minus prediction) can be transformed into a delta time error. This quantity is more constant over time and can be used for identification of the true returns much as the range residuals described above. Again the determined prediction errors can be used to improve the predictions of the future ranges to better distinguish between true returns and noise. This strategy does not work near the closest approach where an along track error cannot be computed from the range residuals alone.

6. Remote Control

A prerequisit for a true remote control is the capability to control all devices and components through the station computer, either automatically or by operator intervention.

Examples:

- Open/close the dome
- Set correction optics in function of ambient temperature
- Switch on/off electronic equipment such as counters, receivers, power supplies etc
- Power-up the laser system
- Setting of beam divergence, laser energy
- Selection of receiver to be used (photomultiplier, SPAD, blue and/or infrared laser beam)
- Initializing of the telescope

Currently all necessary components can be remotely controlled with the exception of the power-up and operational alignment of the laser (this is currently under development and should be realized in early 1999).

The main tracking and control program on the VAXstation can be executed from any remote location by remote login (Telnet) using a standard VT200 terminal emulation program.

```
+----------------------------------------------------------------------------+
| Satellite   :  LAGEOS-2                               Visibility : SUN      |
+----------------------------------------------------------------------------+
| Initialize  :  Maximum   # of Shots :  32     Actual # of Shots :   9       |
|    OK          Necessary # of Hits  :   4     # of Init Cycles  :   2       |
|                                                                            |
| Manual Corr.:  Step:  2" Up/Dn Lf/Rg:   0/  0 Total:   0/  0                |
| Search      :  Step:  2" Along/cross:   1/ -1 Total:   2/ -3                |
|                                                                            |
| Obs.Interval:   0.1 s        ADC 1/2: 125  34          RT-Filter:      0 ns |
|     Window  :    50 ns       Epoch  :        8 ms      Previous :     -1 ns |
| Diverg/Blue :   300 1800     Late by:  -0.003 s                             |
|                                                                            |
| Calibration :  Each 40. obs  ADC 1/2: 112  25          Obs.Value:  89.32 ns |
|                                                                            |
| Statistics  :  Calibr:  120   Faults:  321  No Echo:  2316  Hits:    432    |
|                          34 %                                        21 %  |
| Messages    :  Mode: S  Obs.:  ON  Radar:  OK  ATC :  OK                   |
|                                                                            |
| A 261.5424  E 33.4276  D  180      TRACKING     23-DEC-98  14:15:32.3 12:23 |
+----------------------------------------------------------------------------+
```

Figure 2: Main Realtime Display

In addition the main realtime display as well as the operator keyboard can be duplicated during operation on any remote VT200 terminal or terminal emulation for operator training, debugging or demonstration purposes.

References:

[1] Gurtner, W., E. Pop., T. Schildknecht, J. Utzinger, U. Wild, J. Barbe: "The New Laser and Astrometric Telescope in Zimmerwald". Proceedings of the 10th International Workshop on Laser Ranging, Shanghai, November 11-15, 1996, pp. 78-89.