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Control Software for the ESO VLT

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Abstract

The Very Large Telescope (VLT) project of ESO consists of an array of four optical telescopes of 8m diameter, to be installed at a new site in the Atacama desert in Chile starting in 1995.

The control software is completely distributed, being based on LANs interconnecting microprocessors and workstations, where several users and operators will be active at the same time.

Microprocessors are used in a variety of control functions, including the active control of the shape of the main mirror and compensation for atmospheric turbulence. Dedicated links and antennas are planned for direct communication and remote observation from various European centers.

The main concepts and novelties of the software design are explained.

I. THE VLT PROJECT

A *Main characteristics*

The VLT project has been initiated with the aim to provide European astronomers with a ground based telescope of larger size than those presently available [1].

The VLT concept consists of an array of four identical main telescopes, each having a thin monolithic mirror of 8m diameter. This gives an equivalent total size of 16m, when the four telescopes are used together, which shall be the largest size available on ground telescopes at the end of the 90s. The large size of the array will allow a very high angular resolution (the possibility to resolve details).

Each main telescope has an Alt-Azimuthal mount and is equipped with instruments at the two Nasmyth foci, Cassegrain focus and Coudé focus.

The four main telescopes can be used independently, or in several combined modes. One of the combined modes is the incoherent beam combination in a combined Coudé laboratory.

The other combined modes foresee coherent beam combination in an interferometric laboratory. In this case the use of two or more auxiliary telescopes of 1.8m diameter is also foreseen. These should be moveable on tracks. Optical path differences will be compensated with the use of delay lines and the optical beams are brought to interfere. Astronomical images can then be reconstructed starting from the interference patterns.

The use of a chopping secondary mirror has been proposed.

The VLT site is the Paranal mountain in northern Chile, in the Atacama desert at an altitude of 2700m.

Figure 1 shows the telescope layout foreseen for the top of mount Paranal. The first telescope is due to be installed at the end of 1995, with each following telescope being installed at time intervals of one year.

The whole VLT program including instrumentation will be concluded some years later. This gives a very long timespan for the installation of the VLT and of the control system in particular.

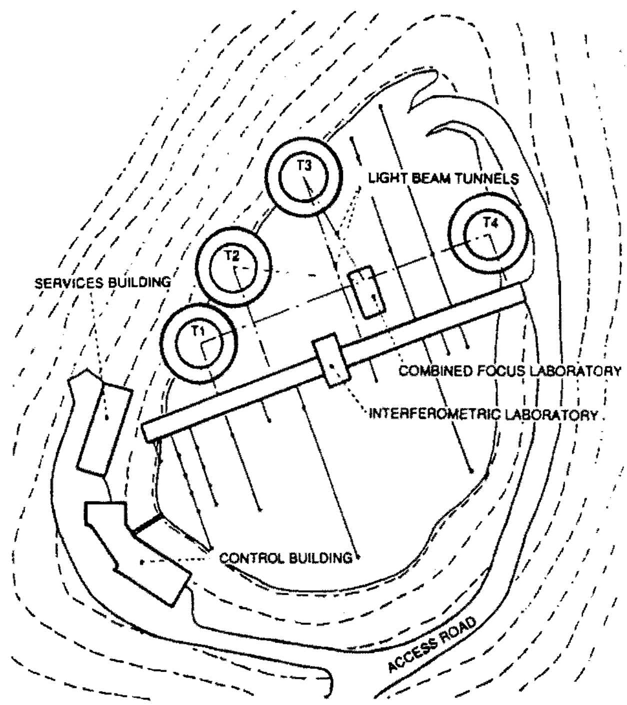

Figure 1: VLT observatory

B *Special aspects*

Special aspects of the VLT telescope with respect to other telescopes are:

- system distribution

  This is implied by the fact that the VLT is an array of four telescopes.

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- active optics

  This is a system of 150 supports for the main mirror, which allow it to change its shape. It is meant to compensate for deformations due to manufacturing errors, gravitational and thermal effects and also low frequency wind load effects on the main mirror.

  The image quality is analysed via a wavefront analyser, and a microprocessor provides the values to the support system.

  The active optics principle has been tested on the New Technology Telescope (3.5 meter diameter) now in regular operation at the ESO La Silla Observatory in Chile. It is thanks to this principle that not only excellent optical quality can be achieved, but also that substantial savings on the weight of the mirrors and on the size and costs of the whole telescope can be made [2].

- adaptive optics

  This system is introduced to compensate for the effects of atmospheric turbulence on the quality of images.

  It consists in applying to a deformable mirror a number of piezo-electric actuators, which compensate in real-time in a control loop for the optical degradation of images.

  This principle has been tested at the ESO 3.6m telescope, but not yet used on a regular basis as part of any instrument.

  The associated multichannel feedback loops require fast and powerful computation. It is acticipated that, for the VLT, human interaction can be eliminated, and procedures can be defined to allow routine use of this system [3].

C *Operational context*

The VLT operation has to cope with a complex environment produced by a multi-telescope, multi-instrument and multi-user context.

- Multi-telescope context

  The VLT software will support the following telescope configurations:

  - Stand-alone configuration

    Each telescope is used alone, allowing individual observing with an 8 m unit telescope.

  - Combined incoherent configuration

    This configuration includes the use of two, three or four main telescopes working either simultaneously on the same object with identical instruments, or via a combined instrument at the Combined Coudé focus.

  - Combined coherent configuration

    This is the configuration used for the VLT Interferometer (VLTI).

    It requires the use of at least two of the four VLT telescopes and of one or more of the auxiliary telescopes. Important aspects are the precise control of the position of the moveable auxiliary telescopes and of their associated delay lines.

- Multi-instrument context

  Normally up to three instruments will be mounted all the time on the main telescopes and additionally one has to consider the combined instrument and the VLT interferometer instrumentation. Therefore the VLT is characterized all the time as having a multi-instrument context.

  Parallel access to all the mounted instruments will be provided, though only one instrument per main telescope has access to the telescope beam (active instrument).

- Multi-user context

  Independently of the location of users (in the control room or at a remote location), they will be able to access any part of the whole set-up with a simple logon and configuration operation. In other words, the whole VLT system will be accessible and controllable from any single user station.

  A monitoring mode might also be important when a problem occurs, for which expert advice is needed and this can only be obtained from colleagues situated remotely (either in Santiago or in Garching). Monitoring will allow them to follow the results of tests performed and investigate how the system is working.

D *Operational requirements*

The VLT shall be operated at different levels: observing, maintenance and test level. This basically corresponds to the needs of the different users, namely observing astronomers, operations staff and software development staff.

Observing astronomers differ very much in experience and many of them are very occasional users of the system.

A system of privileges and protections shall allow operation of the different parts of the VLT at the required level, without interfering with other users.

A capacity of twenty active users at the same time is foreseen, with six additional users who can monitor the work of others.

- Service observing

  Observing, as such, is the purpose of the VLT system, but classical (interactive) observing is the least efficient way to achieve this.

  Service observing, on the other hand, means that the observing programme can be performed by someone other than the proposing astronomer.

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- Flexible scheduling

  Flexible scheduling means the possibility of reacting quickly to changes in weather and other conditions by allocating the optimal observing program for those conditions.

  It requires the use of service observing, as users may not be able to wait for special conditions.

- Automatic observing

  To achieve efficient service observing and flexible scheduling, it will be possible to carry out observations automatically, in accordance with pre-defined sequences of exposures, as is commonly done in space observatories.

  At the same time, one does not want to lose the advantages and the extra flexibility of ground-based astronomy. So whichever scheme is adopted to perform automatic sequences, interaction will be allowed at the desired level (for example, only on error conditions) and at any time the user shall be allowed to break a sequence.

II. VLT CONTROL SOFTWARE

The VLT control software includes the control of the main and auxiliary telescopes, the interferometer and the instruments of the VLT (18 are foreseen at the moment).

All this will be based on a distributed environment of workstations and microprocessors, as described below. The total number of microprocessors for which specific VLT software will have to be written is estimated to be in the order of 150, of about 40 different types.

The total amount of software to be produced, excluding the instruments developed by Astronomical Institutes linked to ESO is estimated to be in the order of 90-100 man-years.

A Data specifications

The final purpose of the VLT software is the acquisition of astronomical data in digital form in the most efficient way.

To achieve this, many other data concerning the telescopes and instruments and control commands will have to be exchanged between different processing units in order to set-up and control telescopes and instruments. Additionally, video and voice data are also necessary (for example, field monitors).

Control information must be transferred, typically in the form of commands and replies from users, to telescopes and instruments. Replies might contain status information and, in general, data concerning instruments and telescopes, to be stored together with the astronomical data.

B Control system distribution

The VLT system is intrinsically distributed and needs user access at any telescope and instrument. This leads naturally to a distributed structure. The implementation plan, with different telescopes going into operation at different times, demands a stepwise implementation of the control system.

When one takes into account the control needs of the various elements, every telescope is itself a distributed system where control functionality and computing power has to be provided.

All the above considerations lead to a control system design, distributed both at the telescope level and again at a higher level, to cope with the distributed architecture of telescopes and instruments.

A distributed system improves the hardware reliability of the whole set-up, as the number of cables is minimized. This has been tested on the NTT.

C Control system layout

Figure 2 gives a schematic view of the VLT control system, which ESO has in mind.

The four main telescopes, subsystems and instruments are shown in the top part at the left. The central part shows the computer and communications equipment located in the VLT control room. The bottom part shows in a schematic form the remote access facility in Garching.

The part on the right at the top shows the Coudé combined focus facility, while the Astronomical site monitor is shown on the right hand side at the bottom.

Additionally there will be a separate control room for interferometry.

D Control system architecture

Referring again to Figure 2, one finds at the bottom (near the control electronics interfacing with telescopes and instruments) the Local Control Units (LCUs) and then a network of coordinating processors (telescope and instrument processors and workstations) and central and remote workstations.

In this respect the hardware layout has a two-layer structure, but the various telescope segments are separated via bridges and gateways from the network backbone.

Functionally, a hierarchical structure with three layers can be implemented in the software, separating the local branches of the local area network from the central backbone, so that the central computers can be seen as the top layer. This offers advantages in modularity and security in the case of operations at the observing level (e.g. a command from a central workstation might go to the coordinating processor of telescope 1 and from there, be rerouted to the appropriate LCU).

At the same time at the test level the normal operational hierarchy can be by-passed and any local controller can be addressed and tested directly from a central workstation (two-layer hierarchy).

The system described:

- supports access from any workstation to all or parts of the VLT,

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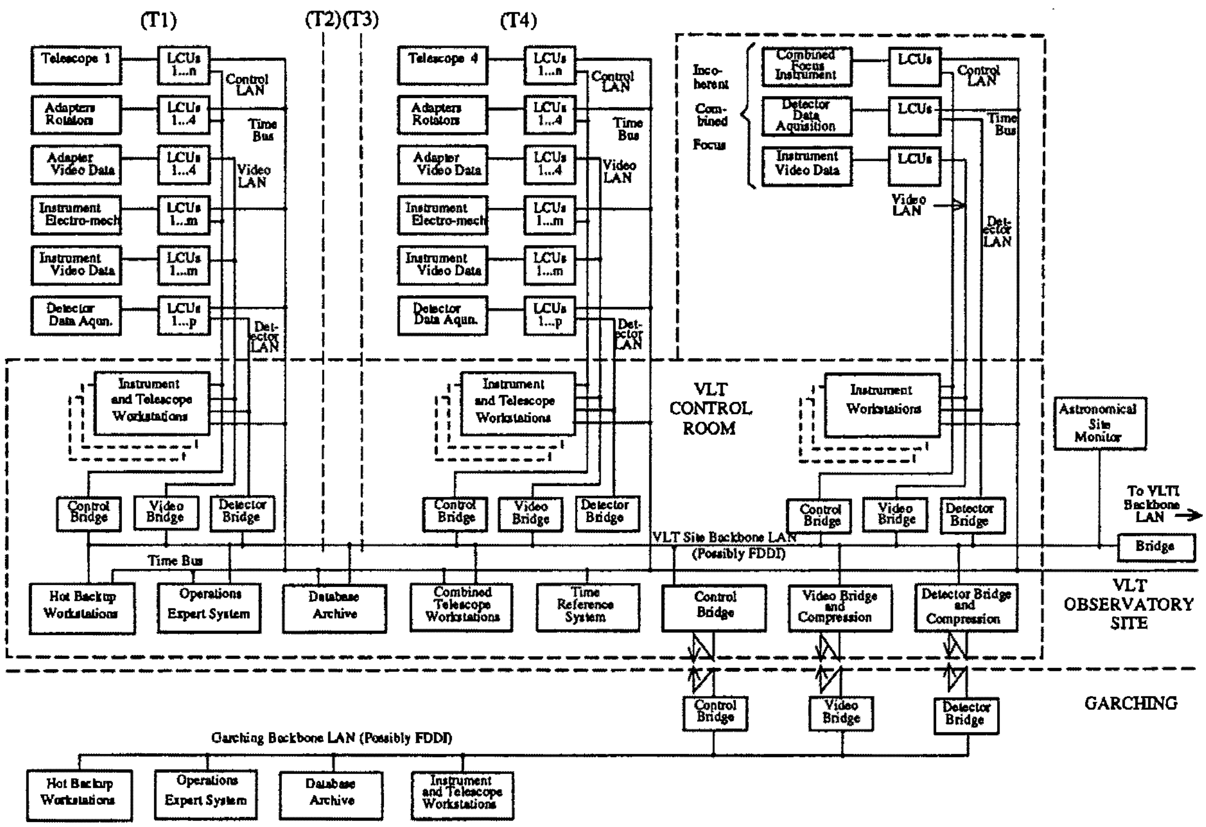

Figure 2: VLT control system

- can be implemented in steps, allowing independent development of the various instruments, and
- implements distributed real-time control at the telescope level, via the LCUs.

Different LANs have been introduced with the purpose of coping with the different requirements represented by synchronisation needs, control data, astronomical data and remote access.

E *Functional Software Structure*

The VLT software can be divided into five major functional blocks:

F *Development model*

The VLT software will be developed according to a precisely prescribed development plan and to methodologies supported by the use of CASE tools.

The purpose of this is to:

- make the development process visible
- provide maintainable software
- cope with the need for expansion of the VLT software.

G *Standards*

Standards have been selected for the computers and the system software to cope with the development phase and to allow a smooth transition to the commissioning phase when the target computers will have been chosen.

The following criteria have been applied:

- Emphasis on development and productivity requirements, including cross-support tools.
- Portability of software (target hardware independence)
- Hardware and vendor independence
- Use of industrial and de-facto standards

For the operating systems Unix System V (with Posix interfaces) has been chosen for the workstations. This is complemented by the X11 window system and OSF/Motif in the area of user interfacing. Communications portability shall be achieved by using TCP/IP and ARPA services. Command handling will be based on RPC. Commercial products are used in the area of the off-line database (Sybase) and as a CASE tool (RTEE). VxWorks is the operating system which has been chosen for the VME-based

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microprocessors (local control units). This product is particularly suitable for a distributed environment and is well integrated with Unix, having the necessary real-time characteristics. The software development language has been defined as being ANSI-C, with a number of restrictions applied to it. This has resulted from a comparison with ADA and C++. There are thoughts that this last could be used in some selected areas.

Communications hardware is IEEE 802.3 for the control LAN and might become FDDI for the data LAN. FDDI will also be used for the workstations backbone.

H Functional Software Structure

The VLT software can be subdivided into two categories : system software (or data acquisition and control software) and specific applications software (in this case Telescope and Instrumentation control).

Figure 3 shows the structure of the VLT software.

The system software will be described in more detail in the next sections.

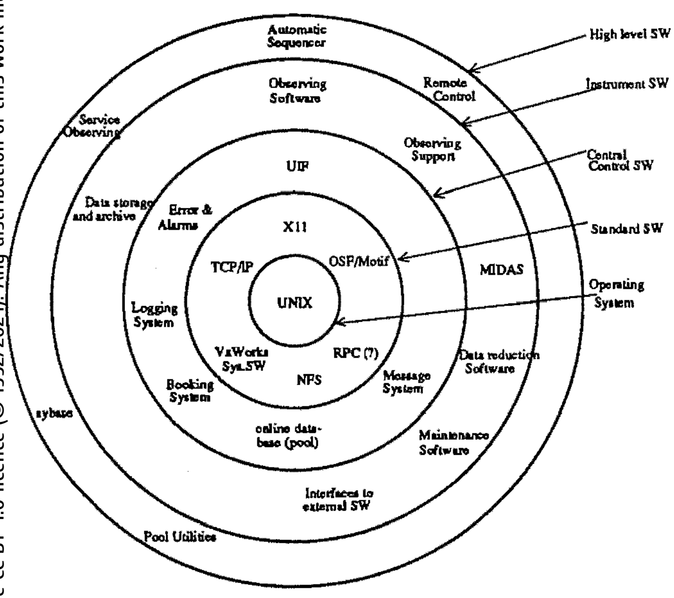

Figure 3: VLT Software Structure

I System Software Structure

This contains all the common services, which allow an open and expandable system such as the VLT to look like one homogeneous entity to the users.

In particular common (non-application-specific) software, including protocols, libraries, utilities, tools, on-line database and interfaces to the external software, user interface tools are part of this.

The system software will contain the following modules:

1. User Interface common tools

   The VLT will accomodate many user stations, locally and remotely (both in Chile and in several sites in Europe). All of these stations, no matter for which instrument or telescope they are used, will have a common "look and feel". This will be achieved by implementing a portable user interface toolkit, based on OSF/Motif, which will be used for the implementation of any particular user interface.

   The user interface will be completely decoupled from control programs, in that the values being displayed or cyclically monitored will come from an on-line database rather than being requested directly from the control programs.

   This will detach user interface issues from program development, and will allow rearrangements in this area easily.

   In this way the variable number of users and monitoring stations will not affect system performances.

2. On-line database

   The control parameters and any other information relating to the telescope, instruments and detectors must be accessible at any operation level and shall be contained in a control on-line database.

   This has to be a real-time database, with the access-critical data based in memory. Access to information in the database must be logical (for example, by name).

   The database must include mechanisms to allow the collection of data from a number of LAN nodes and their use by others. So it must have mechanisms to allow either remote access or it must support data distribution (or both).

   The database must have an interface to general database management systems (DBMS) and conversion tools from/to it via standard interfaces must exist.

   Table-driven applications can thus be easily implemented in a clear and maintainable way all over the system.

   A real-time distributed database with a hierarchical structure has been implemented by ESO for the NTT project [4] and has been ported now to Unix for the remote control of the NTT from Munich (see later remote observing).

3. Communications software

   A generalized protocol will be used across all software packages for command passing at the program-to-program communication level. Commands should

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have a logical nature and shall not refer to any specific physical address.

Cascade routing of messages will be supported to allow remote access.

4. Common LCU software

This includes all the common microprocessor software, contained in the LCUs, but not yet application specific.

Command passing, downloading of initialisation files, common rules to access and exchange information, synchronization methods, lists of common generic commands and boot procedures have to be incorporated in this software.

III. VLT REMOTE OBSERVING

Remote observing means that users shall be able to observe from a remote site, Santiago, Garching or even home Institutes in Europe. This is explained in detail in [5], as ESO has already been running a rather unique regular remote observation service from Munich with the Observatory in Chile, for about 4 years.

The extent to which realistic observing conditions can be reproduced depends, of course, largely on the link bandwidth available. Experience with previous telescopes shows, however, that, even with very limited bandwidths, remote observing can be implemented, provided the software is suitable for this.

Remote observing, using the VLT will be indirect. Users will have an interaction possibility, but normally via operators at the VLT or in Garching, or via the scheduler program and shall not control any part of the VLT directly.

Remote monitoring is the simplest level of remote observing. It is sometimes called 'eavesdropping'. It is a requirement for the VLT operation and will complement service observing, making it friendlier for users.

The remote observing facility in Munich will be linked, according to the current plans, with the site at Paranal with a dedicated leased satellite link at 1-2 Mbit/sec using ESO-owned antennas.

IV. CONCLUSIONS

The VLT system software is now in the analysis phase. Reuse of some components is planned, while for new software ESO is planning to take advantage of collaborations with Astronomical Institutes and industry.

There are a lot of areas in the VLT control software, which are common to other control applications in physics. The common denominator for high energy physics, fusion research and astronomy being the production of fairly high amounts of scientific data, for later analysis and also with on-line processing requirements.

Some relevant areas for possible collaboration include:

- UIF portable toolkits (although specific applications will be different)
- Command handling in distributed environments (application level protocols and internal syntaxes).
- Use of on-line distributed databases in control systems, in combination with commercial database management systems. Computer and software vendors are also starting to enter this area.

These are some of the areas in which collaboration and exchange of information can play an important role (see also [6]).

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