Status of VLTI control system: how to make an optical interferometer a data producing facility

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ABSTRACT

After having established routine science operations for four 8 m single dish telescopes and their first set of instruments at the Paranal Observatory, the next big engineering challenge for ESO has been the VLT Interferometer. Following an intense integration period at Paranal, first fringes were obtained in the course of last year, first with two smaller test siderostats and later with two 8 m VLT telescopes. Even though optical interferometry today may be considered more experimental than single telescope astronomy, we have aimed at developing a system with the same requirements on reliability and operability as for a single VLT telescope. The VLTI control system is responsible for controlling and coordinating all devices making up VLTI, where a telescope is just one out of many subsystems. Thus the pure size of the complete system increases the complexity and likelihood of failure. Secondly, some of the new subsystems introduced, in particular the delay lines and the associated fringe-tracking loop, have more demanding requirements in terms of control loop bandwidth, computing power and communication. We have developed an innovative generic multiprocessor controller within the VLT framework to address these requirements. Finally, we have decided to use the VLT science operation model, whereby the observation is driven by observation blocks with minimum human real-time interaction, which implies that VLTI is seen as one machine and not as a set of telescopes and other subsystems by the astronomical instrument. In this paper we describe the as-built architecture of the VLTI control and data flow system, emphasising how new techniques have been incorporated, while at the same time the investments in technology and know-how obtained during the VLT years have been protected. The result has been a faster development cycle, a robustness approaching that of VLT single dish telescopes and a "look and feel" identical to all other ESO observing facilities. We present operation, performance and development cost data to confirm this. Finally we discuss the plans for the coming years, when more and more subsystems will be added in order to explore the full potential of the VLTI.

Keywords: VLTI, control system, interferometer, software engineering

1. INTRODUCTION

After more than ten years of dreams, plans, simulations, design and development the Very Large Telescope Interferometer (VLTI) became reality last year, when interferometric fringes were obtained using stellar beams from two 8 m diameter VLT unit telescopes (UT). Located at the Paranal Observatory in Chile, the purpose of VLTI is the coherent combination of light beams gathered by two or more telescopes[1]. The amplitude and phase of the resulting fringes, together with the known distance between observing telescopes (baseline), give information of the image structure corresponding to an angular resolution of sub milli-arcseconds. In order to maximize the choice of baselines the layout of the Observatory (Figure 1) provides four UTs and 30 observing stations for relocatable 1.8 m auxiliary telescopes (AT), giving baselines between 8 and 200 m in different angles. The VLTI near infrared commissioning instrument (VINCI), operating in K band and located in the interferometric laboratory, performs the combination of two beams using fibre optic techniques[2]. Because the delivery of ATs is scheduled only for next year, the photon collection capacity was complemented early last year with two 40 cm test siderostats (SID), which plug into the observing stations and functionally deliver the beams to VLTI as they would have been UTs or ATs, allowing VLTI integration and commissioning to proceed at full speed.

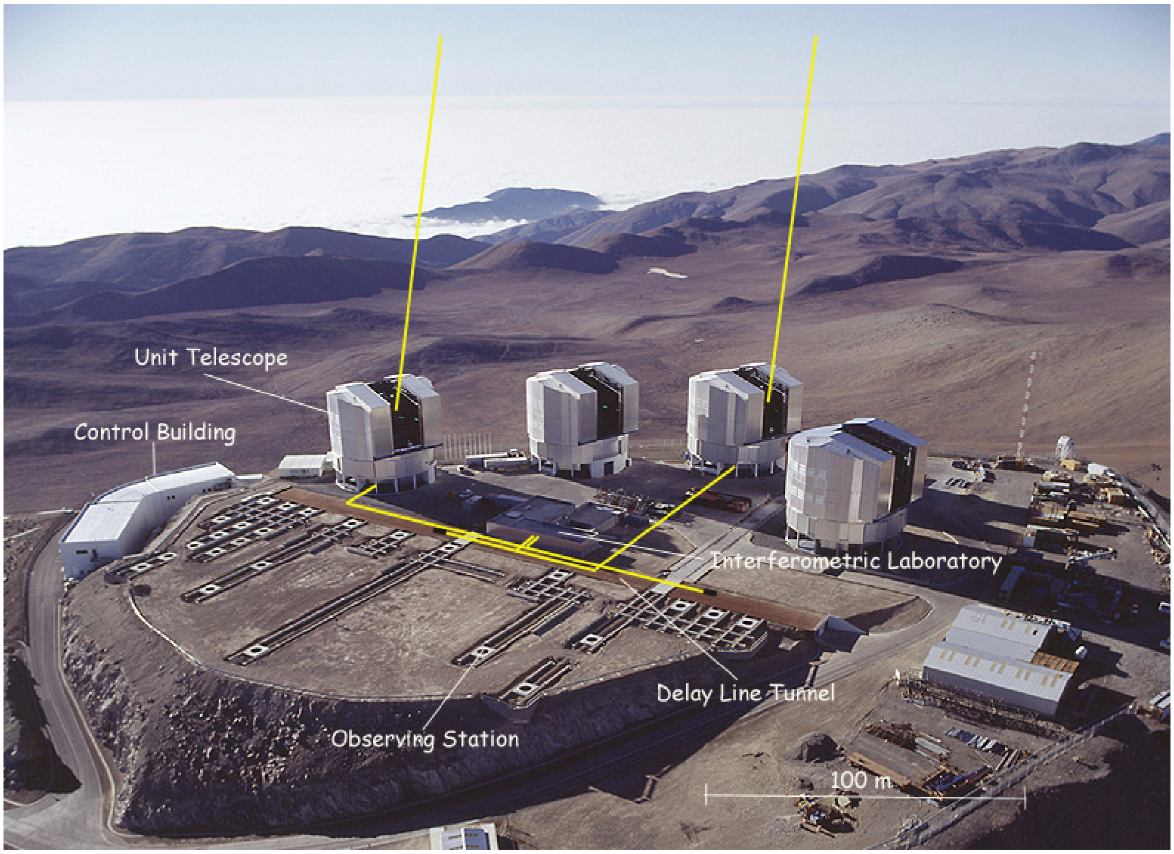

Figure 1. Aerial view of the VLTI site illustrating the light paths when using two UTs

2. OVERVIEW

The light collected by the primary mirror (M1) of each observing telescope is directed through the Nasmyth focus (M2, M3) down to the Coudé station by means of the Coudé optical train (M4-M8). The Coudé relay optics (M9-M11) inject the light beam into the delay line tunnel via a light duct (Figure 2). The Coudé guide probe is an XY-table located below the dichroic M9, transmitting visible light to the probe and reflecting infrared light towards VLTI. The probe contains opto-mechanical elements to select one out of many sensors to perform guiding, field stabilisation (fast tip-tilt correction) or adaptive optics. The tip-tilt loop is closed on M2 for the UT and M6 for the AT. UT adaptive optics will be installed next year replacing M8 with a deformable mirror. M10 in Coudé focus is motorized to control the lateral location of the pupil.

The collimated corrected beam is redirected (M12) towards the assigned delay line housed in a 158 m long subterranean tunnel. Because there has to be at least one M12 per light duct it could happen that another M12 will obscure the beam to the delay line. It is planned to remotely control all M12 units using robotic lifting arms, but currently the M12 has to be replaced manually when VLTI is reconfigured. The purpose of the delay lines is twofold, to compensate for the optical path difference (OPD) between the different arms of the interferometer and to transfer the pupil. Each delay line consists of a retroflector (cat's eye in Cassegrain configuration, consisting of three mirrors M13-M15), which can be transferred over a distance of 60 m. The translation is two stages, where the first stage is a carriage rolling on rectified rails and the second stage is a piezo transducer located at the main focus at the cat's eye. The position control loop is closed at 2 kHz using a high accuracy laser metrology system giving a performance better than fifty nanometer position error RMS[3]. In order to control the longitudinal location of the pupil, M15 will be replaced later this year with a variable curvature mirror (VCM), where the curvature is controlled in open loop through an overpressure chamber.

After the retroflection from the delay line the beam is reflected by M16, mounted on a translation stage, to the assigned input channel in the interferometric laboratory. The switchyard (M17) allows the selection to redirect the beam to a beam compressor (required to compress the beam from UT and siderostats) or directly towards the beam combining instruments. After the switchyard, the instrument feeding optics direct the beam to the selected instrument or, using dichroics, to a combination of instrument and fringe sensor. A dedicated fringe sensor operating in H band will be installed next year in order to close the fringe tracking loop on the delay lines at 2 kHz.

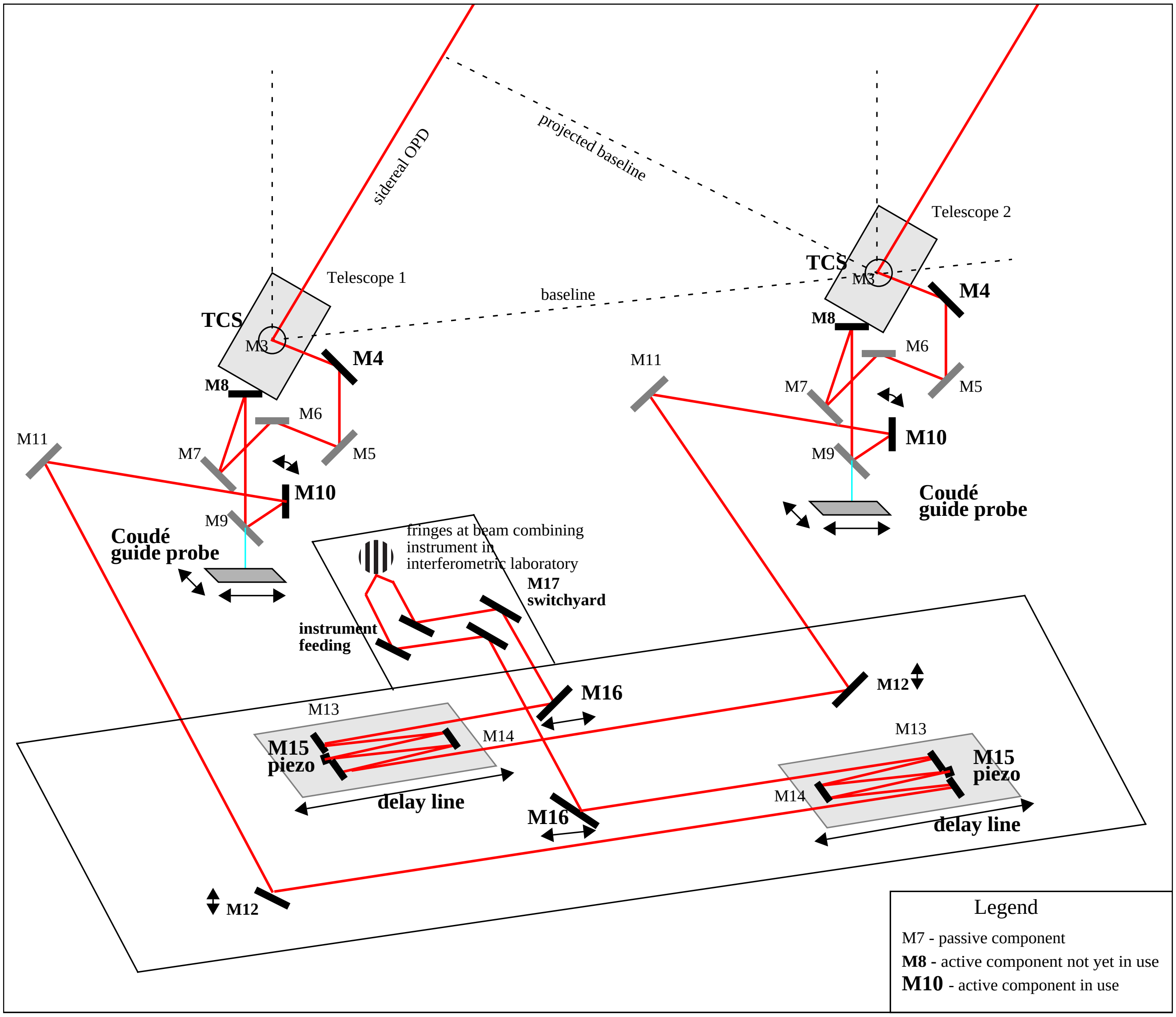

Figure 2: Illustration of optical layout and active components of the control system

At the entrance of the instrument each beam has been reflected 21 times (with beam compressor) over a distance between 100 and 300 m after entering the telescope and is subject to the correct behaviour of 20 computers.

3. EVOLUTION OF STANDARDS AND SOFTWARE ENGINEERING

The VLTI control system is based on the standards developed for the VLT, e.g. a networked distributed multi platform architecture consisting of VME bus Local Control Units (LCU) running VxWorks and UNIX workstations. An ESO developed common software layer, providing standard services like communication, database, logging, user interfaces as well as application frameworks implementing standard behaviour, is provided on top of the operating system. Synchronization between control units is achieved by the VLT time reference system, a dedicated time bus distributing absolute UTC time. A reflective memory network provides a mean to exchange data deterministic and with low latency between different control units. This has been documented extensively elsewhere[4,5,6,7] and will not be repeated here.

These standards, originating in the early nineties, are continuously evolving by upgrading I/O boards, CPUs, workstations, operating system versions and software. Today the Paranal Observatory is operated by more than 60 workstations and 100 LCUs, all running the ESO common software with local applications on top. Out of these, 14 workstations and 10 LCUs are used exclusively by VLTI. Within the next two years it is planned to add 10 workstations and 21 LCUs to VLTI. The ESO common software consists today of 1.8 million physical source lines of code (SLOC), the telescope control software of 400.000 and VLTI applications of 200.000. These numbers have been obtained using sloccount, developed by David A Wheeler (http://www.dwheeler.com/sloccount), including only "non-blank, non-comment lines". We expect the code for VLTI applications to double in the next two years. Once per year the software on all computers at Paranal is upgraded to the yearly software release, further emphasising that these standards are alive and evolving along with progress in technology.

The software engineering of VLTI also follows the standards developed for VLT[8]. The main characteristics are a set of programming standards applicable to the supported programming languages; C, C++, tcl/tk and Java, a software configuration and archive system based on software modules, a software integration tool to facilitate installation of a complete subsystem from a set of modules of certain versions, a software problem report system and tools to build regression tests. The importance of standards and configuration control cannot be overestimated considering the amount of code and the distribution of development, not only limited at ESO sites (Garching, Paranal, La Silla, Santiago), but also at approximately 20 external sites of industry and instrument consortia.

Design methodologies have followed the trends starting with structured methodologies (Ward-Mellor) in the mid nineties and moving to today’s object oriented analysis and design. Lately, Unified Modelling Language (UML) and associated tools have been introduced in the development cycle.

The cost of developing the VLTI application software up to now has been 20 people years, including all phases on the life cycle (analysis, design, coding, testing). This gives a productivity of 48 SLOC/day (assuming 210 working days per year), which compares favourable to industry standards[9], although such comparisons should be taken with a big pitch of salt. We can however compare the number to other earlier ESO projects and, as expected, we see an increase of up to 50% in productivity. It is clear that the experience and culture developed during many years of work for VLT are major contributors to this result. It is more difficult to conclude if new design methodologies have influenced this result or not. In our opinion it is not what tools and methodology you apply, but it is the way you apply them that matters.

Some of the main new requirements for VLTI, compared to conventional telescope control system, are adaptive optics, fringe tracking and related subsystems. The fringe tracking loop can be compared to auto guiding or field stabilisation for telescope control, but having tougher requirements on control bandwidth, computing power, timing determinism and a larger uncertainty which control algorithm will work under real conditions. Simulations indicated that these requirements could not easily be met using existing VLT standards. Furthermore, it was identified that similar requirements existed for a number of the new subsystems. This led to the decision to extend the standards and develop a generic high performance real-time controller within the VLT framework. The requirements for such a controller can be summarized as follow: hard real-time constraints with high sampling frequencies of up to 20 kHz, a standard VLT interface to the outside world, the possibility to change the control algorithm as well as parameters at run-time without having to recompile or reboot, and the possibility to synchronize and trigger the control algorithm with the VLT time reference system.

The requirements formulated above are normally addressed with two different approaches. Firstly, using mathematical computation interpreters, like Matlab, extended with I/O capability. The advantage of this approach is that parameters and algorithm structure are available to the user at runtime, but normally at the expense of overall performance. Secondly, using code generation tools for dedicated CPU platform, like Simulink Real-Time Workshop. The generated algorithm is efficient and predictable, but the major drawback is that the structure of the algorithm is fixed at run time.

The ESO developed tool for advanced control (tac) combines the advantages of these two approaches. The principle is based on the concept of function blocks. A control algorithm is described by a set of function blocks linked together, where each function block has one or many input signals, a known transformation and one or many output signals. A set of standard function blocks exists in a compiled library and new customized function blocks can be added. Input/Output access using dedicated boards is described and coded as function blocks. The selection and connection of function blocks are evaluated at run time, allowing the user to change the control algorithm as well as parameters without the need to recompile or reboot.

Traditionally high performance digital controllers are implemented using digital signal processors (DSP) and there are some examples of this approach at Paranal. However, although DSP is not excluded in the design of tac, we have chosen to use standard power PC (PPC) boards. The main reason for this choice is maintainability. DSP applications tend to be very customized and are implemented using some DSP available at the time of design with no clear path for upgrading to future faster DSPs. The knowledge of the DSP code is often limited to one person, who may not be around a few years later. Therefore DSP applications are hard to maintain and such applications are seldom upgraded even if faster hardware, which could result in performance gains, becomes available on the market. Using standard PPC boards the problem of maintainability does not exist, because porting follows the evolution of the VLT standards and a large pool of software engineers knowledgable about this architecture exists within the organization. In addition today's top-end PPC boards outperform most DSPs on the market.

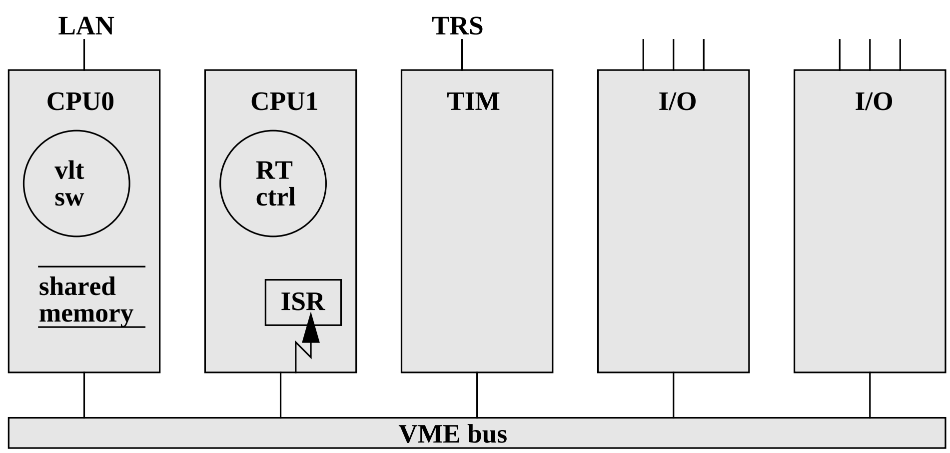

Figure 3. Example of multi processor tac application using standard VLT components

Figure 3 shows the architecture of a typical tac application. In this example tac has been deployed on two PPC CPU boards, where one of the boards is assigned exclusively to the real-time control algorithm. CPU0 implements the standard VLT interface using components from the ESO common software. This CPU also holds the shared memory used to implement bidirectional communication channels between the two CPUs based on message queues. CPU1 runs one application task, the real-time controller, which is responsible for processing requests from the tac server running on CPU0 and for managing the periodic execution of the control algorithm implemented as an interrupt service routine (ISR) and triggered by the time reference system. In order to avoid non deterministic resolution of concurrent bus accesses, the shared memory is located on CPU0 and all IO are exclusively dedicated to the tac RT algorithm, leaving VME bus under complete control of CPU1.

4. VLTI CONTROL SYSTEM ARCHITECTURE

We start the discussion of the VLTI control system architecture with a quick recapture of the ESO data flow model[10], which is illustrated in Figure 4 in a simplified form.

The Principal Investigator (PI), after having been allocated observing time but well before the observation, defines the observation using the phase 2 proposal preparation tool (p2pp). With this tool all parameters required to perform the observation are defined in such a way that the control system can execute it. These computer readable files, called observation blocks (OB), are saved and stored in a database, ready to be queued for execution, either manually or automatically, depending on program rating, target coordinates, observing conditions, configuration etc. The actual execution of the OB is carried out by a staff astronomer supported by an operator, regardless of the observing mode (i.e. visitor or service mode), by fetching the next OB in the queue using BOB (broker of observation block). Starting execution causes tcl/tk based templates to pick up the parameter values and to forward commands to the observation software (OS), which forwards relevant commands to the telescope control software (TCS), instrument control software (ICS) and detector control software (DCS). Although it is technically possible to execute the OB without human interaction, in practice the operator has to confirm certain actions and has the possibility to intervene with manual corrections in case some subsystem malfunctions. During the execution the control system produces FITS data files, which are delivered to the archive system and from there to the pipe-line. Finally, after off-line quality control, the data are delivered to the PI.

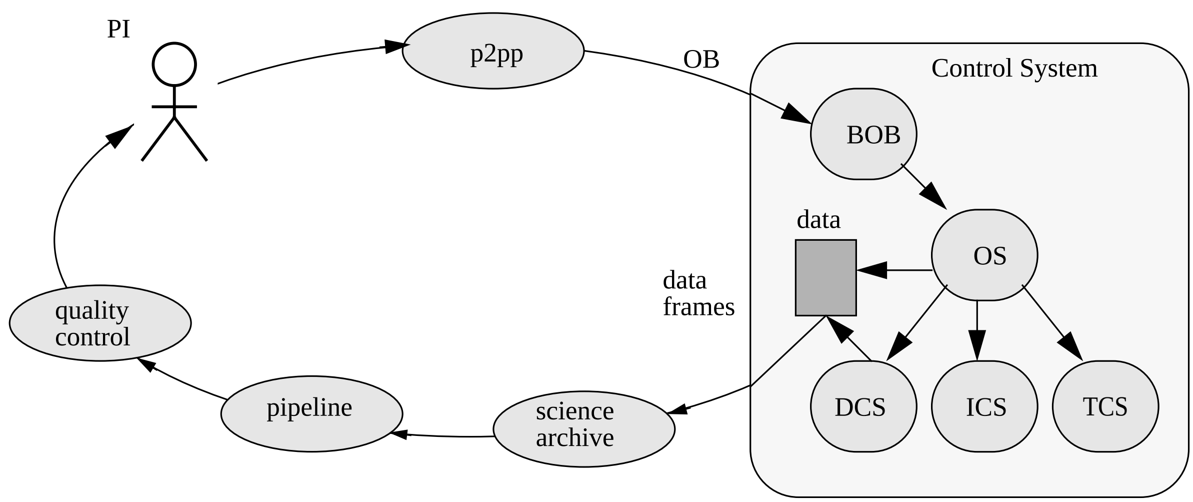

Figure 4. Data flow model showing flow of data from observation preparation via execution to delivery of scientific data

It was decided early on that also VLTI observations should follow the ESO data flow model in order to take advantage of the existing infrastructure and experience. Since VLTI uses multiple telescopes as well as the delay line control system (DLCS) and the artificial source and alignment control system (ARAL), we expanded the architecture by introducing the Interferometer Supervisor Software (ISS) as the highest hierarchical layer of the VLTI control software (Figure 5). A further complication was caused by the fact that the UTs were in operation, without any Coudé focus, making it difficult to integrate and commission a new focus without seriously disturbing science operation in the other foci. We therefore defined, from a control system point of view, the UT Coudé focus as a subsystem of VLTI as there are no other users (instruments) of this focus.

The interface between OS and ISS (TCS) was maintained by making sure that ISS represents VLTI as one entity, not as a set of telescopes and other subsystems. ISS is the single point of contact to VLTI from the instrument, which is not allowed to communicate directly to any telescope or other subsystem of VLTI (an exception to this is when an instrument acts as fringe sensor). Commands are sent from OS to ISS, which broadcasts them to all relevant VLTI subsystems and only one set of status information, e.g. telescope coordinates, are reported back to OS. An important property of the architecture is that OS and its observation templates should not be aware of which telescopes and what type of telescopes are currently part of VLTI.

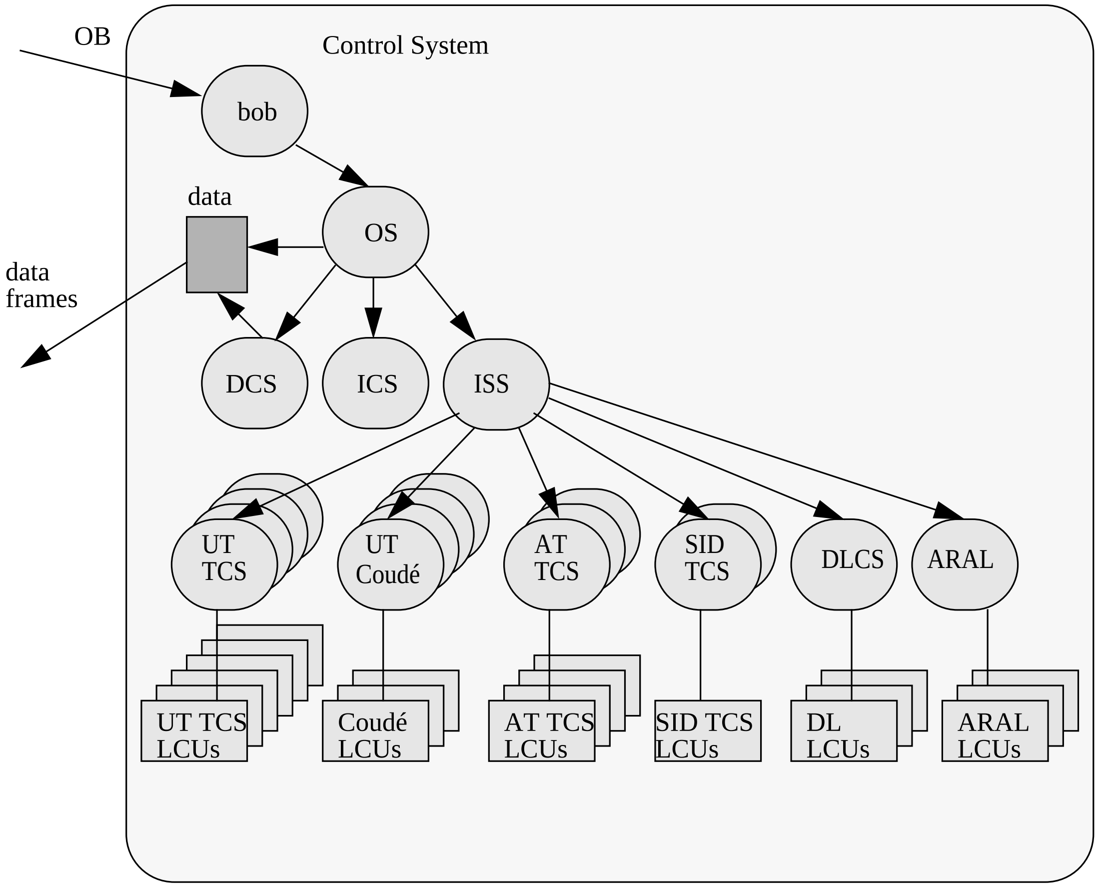

Figure 5. Expanded control system for VLTI with ISS as the highest hierarchical layer and single point of contact

It is worthwhile to point out some differences between telescopes, which have to be hidden by ISS. The most complex scenario comes when using UTs, because ISS has to sequence commands between TCS and the Coudé guide probe. The UT TCS active optics loop has to be closed using the Shack-Hartmann sensor in Nasmyth focus and therefore a Nasmyth guide star has to be acquired and maintained on the sensor by the Nasmyth guide probe, before the Coudé loop can be closed. We introduced a new concept of probe guiding, whereby the Nasmyth probe guides itself without affecting the telescope using the Nasmyth guide sensor. The main guiding loop is closed using a four-quad avalanche photodiodes sensor in the Coudé guide probe acting on M2 over the dedicated rapid guiding LAN at typically 100 Hz. M2 offloads to the main axes with low frequency. This system locks the telescope as well as removes the tip-tilt component of the atmosphere. In the case of siderostats the only guiding possibility is conventional auto guiding using the science target as guide star. By letting ISS take care of these differences the instrument OS can use the same observing templates for both cases.

One of the functionality of ISS is to handle the configuration of VLTI and the telescope array, e.g. the selection of telescopes, the assignment of delay lines and the selection of the instrument by means of feeding optics. The configuration determines with whom ISS will communicate and is implemented simply by a table with one row of data per interferometric arm. The table is used to reconfigure access to all subsystems such that commands are only forwarded to and status only retrieved from telescopes currently configured as part of VLTI. Special care has to be taken when using UTs to avoid commanding a UT used in single telescope mode. A handshake process, whereby the telescope operator has to switch the focus of the UT to Coudé before it can be configured as part of VLTI, ensures this. The configuration also includes an estimate of the optical path length (OPL) for each interferometric arm based on geometric computations using accurate position coordinates of all optical elements. For a new baseline (configuration) these data are used as a first approximation of the OPD model, which is later refined by the DLCS.

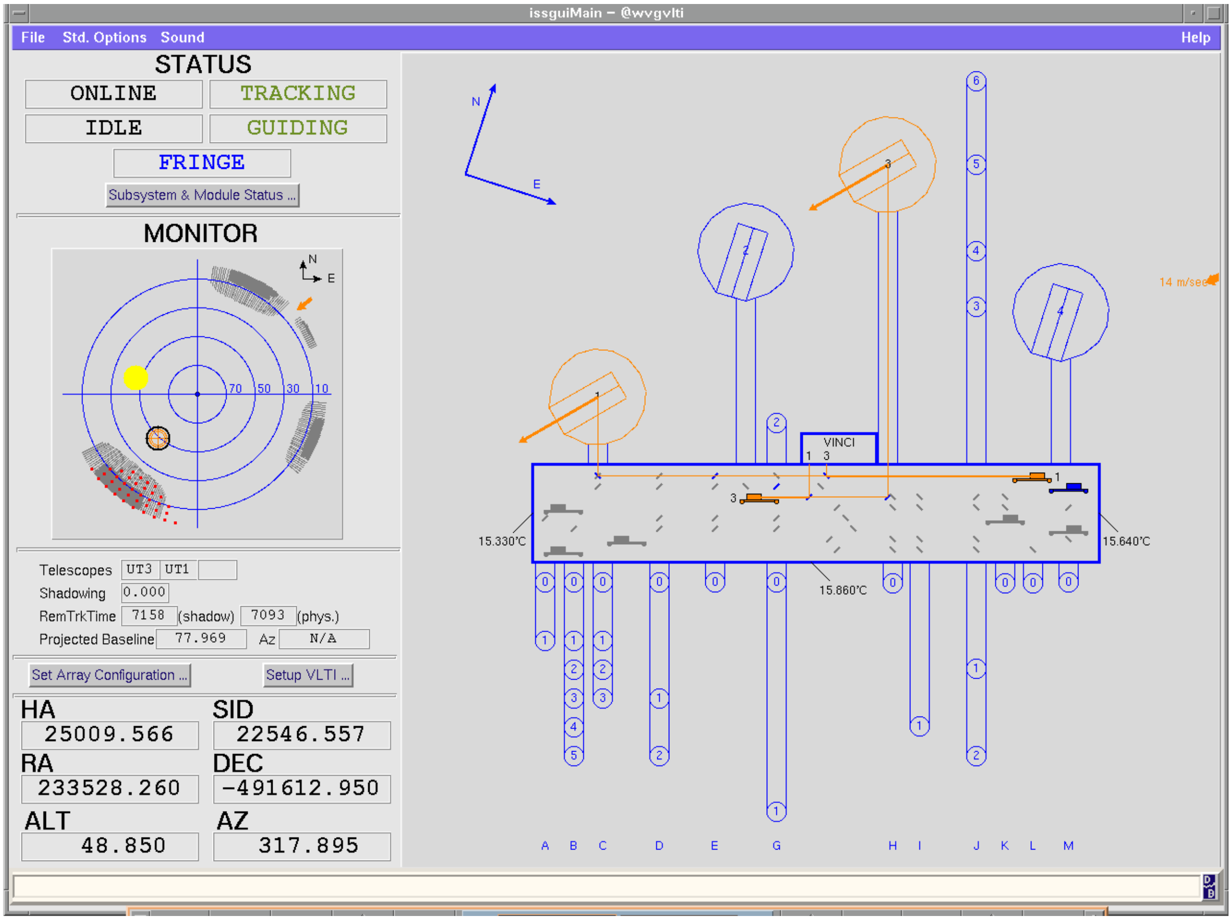

Figure 6. Snapshot of VLTI main graphical user interface using two UTs during fringe tracking

On the main VLTI graphical user interface the configuration and actual status are visualized by highlighting telescopes and delay lines which are currently part of VLTI, by the light path, by animating the actual positions of telescopes and delay lines as well as displaying environmental parameters like wind speed, wind direction and position of the moon. In Figure 6 VLTI has been configured to use two beams from UT1 and UT3 and delay lines 1 and 3. Graphical representation of light paths and actual positions gives easy to interpret information of bad configuration, obscurations, optimal delay line positions, wind effects etc. The dartboard to the left is a representation of telescopes and VLTI altitude, azimuth positions in polar coordinates. This widget also visualizes areas not observable due to shadowing of other telescopes (shaded - grey) and due to limitation of the stroke of the delay lines (dotted - red). This information is static for a certain configuration, but obviously changes when VLTI is reconfigured.

Figure 7 shows another snapshot of the same graphical user interface when using a different configuration, two siderostats located at observing stations E0 and G1. The observable area is smaller due to stricter physical limits of the siderostats mount (black) and obscuration by its own periscope (to the south).

There are many examples where time synchronization between physically distributed control units is required. Obviously it is not possible to pull dedicated cables between all possible combinations of units needing to be synchronized. This problem is solved by the VLT time reference system, which distributes absolute time (UTC) over fibre optic links all over the observatory. A dedicated VME board receives the signal and re-synchronizes itself at 1 Hz. This board can be programmed by the local application to generate VME interrupt with an absolute resolution on 10 µsec.

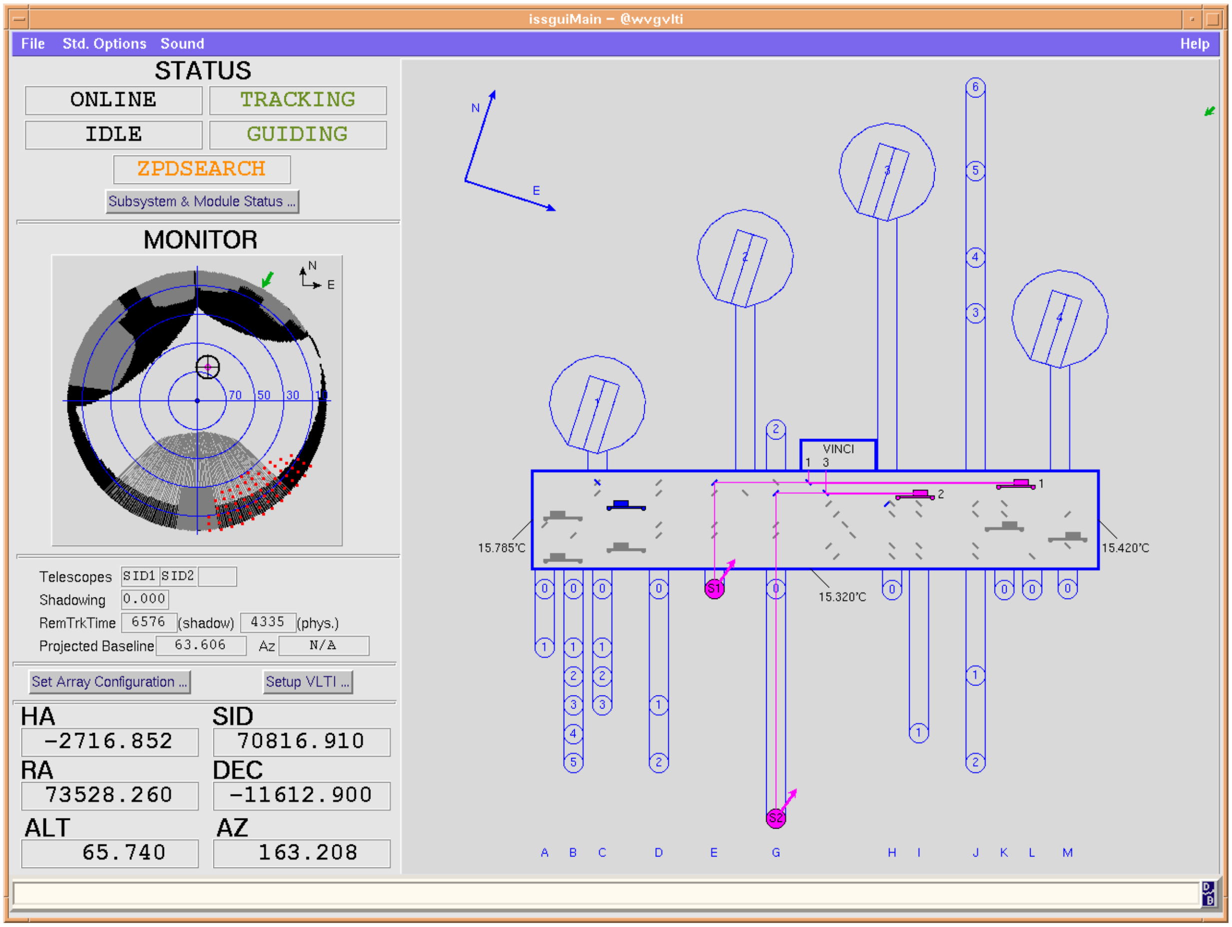

Figure 7. Snapshot of VLTI main graphical user interface using two SIDs located in stations E0 and G1

A typical application of this mechanism is synchronized chopping. After the chopping parameters (frequency, throw, angle, ratio) have been distributed to the relevant control units by ISS, a start command is sent with an absolute time, e.g. one second in the future, as parameter. Triggered by the time reference system the actions will then start on all distributed local control units at the same time. Figure 8 shows the setpoints and actual positions for one of the M2 chopping axis of UT1 and UT3. Data has been sampled locally at each M2 unit at 2 kHz including absolute time in order to combine the two data sets afterwards. Chopping is at 5 Hz and the fast tip-tilt loop, operating on the same axes as chopping, is closed (at 100 Hz) when the beam is on target and opened when the beam is on sky. In fact we implemented this at the tip-tilt sensor located in the Coudé focus by synchronizing also these control units to send tip-tilt corrections only when chopping stage is on target.

The heart of the VLTI control system is DLCS, responsible for positioning the delay lines, fringe searching and closing the fringe tracking loop. The OPD between two interferometric arms consists of two parts, the static part due to the configuration and the dynamic part due to the sidereal motion (see Figure 2). In addition the OPD is influenced by the atmosphere. VLTI currently operates with one delay line in a fixed position, but under position control (reference delay line), and the others tracking the sidereal motion based on the target reference coordinates. For a new baseline a rough estimate of the static OPD is given by ISS as mentioned earlier. This can be compared with a telescope without pointing model trying to find the target object. Just like a telescope pointing model speeds up the target acquisition the OPD model speeds up the fringe acquisition by taking into account geometric misalignment and other systematic errors[11]. The supporting software IPHASE[12] operates in a very similar way to the TPOINT package for telescope pointing modelling. Delay line positions are recorded when fringes are detected for different stars covering the complete sky. These data are analysed with the IPHASE package which determines the geometry of the interferometer including the relative locations of the two telescopes and various runout effects in their and the delay lines' mounting. The resulting terms and their values are then taken into account when computing blind trajectories reducing the OPD error and therefore speeding up the fringe acquisition. The OPD modelling has to be repeated for each pair of interferometric arms.

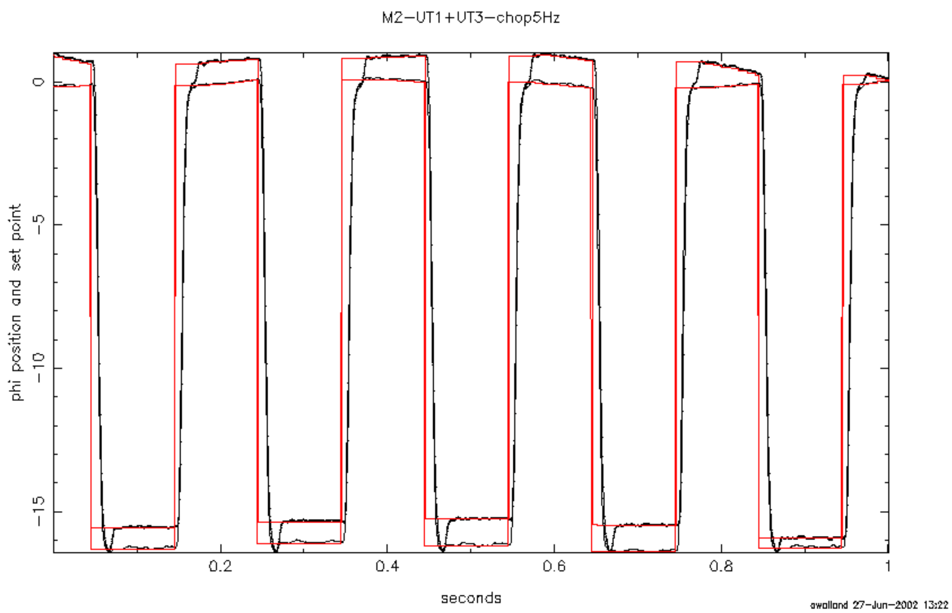

Figure 8. Synchronized chopping with two telescopes using the time reference system. The fast tip-tilt loop is closed when on target (positions corrected at top of graph) and opened when on sky (no corrections at bottom of graph).

Even with a perfect model the OPD will not be zero and it is therefore necessary to search for fringes by superimposing an offset trajectory on the blind trajectory. The offset trajectory can be pre-programmed or generated in real-time by the fringe sensor. Currently VLTI does not have a dedicated fringe sensor, but the instrument VINCI acts also as fringe sensor. VINCI internally scans the OPD using a piezo transducer. During fringe searching VINCI requests an offset to the delay line between each internal scan until fringes are detected. The communication of offsets is performed over a low latency reflective memory network connecting any fringe sensor, a dedicated OPD controller and all delay lines. All messages from any fringe sensor to the delay lines are passed via this OPD controller, which applies filtering and control algorithms. The main justification of the OPD controller is to have maximum dedicated computing power for the control algorithm and not to share it with fringe sensing functionality, but also to have the freedom to use different fringe sensors and handle administrative tasks like keeping track of which delay line to command. The OPD controller is therefore implemented as a tac application. When fringes are detected the OPD controller asserts a flag on the reflective memory network and the system switches to fringe tracking. The OPD controller now uses coherence or phase values produced by the fringe sensor to compute and send offsets to the delay lines in order to lock the fringes. In case of VINCI the frequency of the fringe tracking loop is very small, a few Hz depending on instrument parameters, and mainly due to atmospheric changes the fringes move slightly from scan to scan. At the beginning of next year an internal fringe sensor will be added to the system and the fringe tracking loop is then expected to operate at 2 kHz. The parallel of this in the telescope world is slow auto guiding and very fast field stabilisation.

The offset applied to the tracking delay line by the OPD controller, when fringes are detected, is logged in the engineering data stream. These data provide metrics regarding the performance of the OPD model and VLTI in general over time. Figure 9 shows the data over a three month period at the beginning of this year, where the y-axis has been scaled to +/- 10 mm and the x-axis is the day of the year. These data are very noisy and have to be interpreted with great caution. One major source of error is the use of an incorrect OPD model, either due to human error or software error. Another reason is a false detection of fringes due to a not 100% robust fringe detection algorithm. Bad target coordinates will also influence these data because the blind trajectory is computed based on the reference coordinates given by the user. The reliability problem of the delay line metrology system, briefly discussed in next section, is also introducing noise in the data. Nevertheless, computing the RMS on a monthly basis, we got 2.05 mm in January, 0.96 mm in February and 0.68 mm in March. These figures are still far from what we aim at and this will be one of the main areas of work in the coming year.

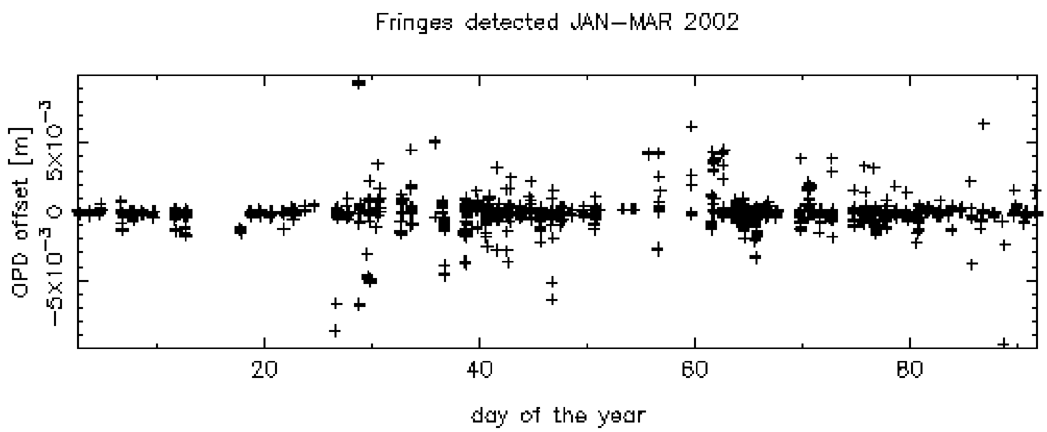

Figure 9. OPD offset where fringes were detected in the period January to March 2002

5. PROBLEMS AND FUTURE PLANS

Currently the large majority of technical down time and degraded performance are caused by two major problems. The position measurement system of the delay lines consists of a coarse (30 µm) absolute encoder system, used only at initialization time, and a high accuracy relative laser metrology system. The metrology system relies on an accurate and very sensitive alignment and the laser uses low power in order to minimize stray light. This makes the system very sensitive to temperature and other environmental disturbances. A temporary loss of the metrology signal, or glitch, causes the position measurement system to deliver a position of zero and the position controller to drive the carriage away. When the metrology system recovers the absolute position is then incorrect. We have built a recovery system into the software whereby the glitch is detected and the system recalibrates itself using the coarse absolute encoder system when the metrology recover, but this is obviously not a solution of the problem. The second major problem is the fibre beam combiner inside VINCI. The technique and material used in the fibre splicing has turned out to be extremely sensitive to temperature changes and seems to degrade with time. Manual interventions are required on a monthly basis to maintain performance. Both problems are under study with high priority in order to find permanent solutions.

The coming years will again be a major challenge to VLTI when a substantial amount of new components and subsystems will be added and integrated. At the end of this year the delay lines will be equipped with controlled variable curvature mirrors and additional motorized feeding optics will be added in the interferometric laboratory. At the same time the Mid Infrared Interferometric instrument (MIDI) operating at 10 µm will arrive at Paranal[13]. Early next year all motorized switch yard and instrument feeding optics devices will be completed and the fringe sensor will be installed. Two unit telescopes will be equipped with adaptive optics (the other two following the year after) and the second scientific instrument, the Astronomical Multi-beam recombiner (AMBER) operating in K-band, will arrive[14]. Both the fringe sensor and AMBER operate with three beams. In the course of 2003 Paranal will also receive three auxiliary telescopes[15] dedicated to VLTI and three additional delay lines. In 2004-2005 the dual-feed facility PRIMA, currently starting the design phase, will allow VLTI to observe much fainter objects.

6. CONCLUSIONS

The VLTI control system is being built based on the evolving technology and experience from the VLT. We believe we have found a good balance making use of these assets and at the same time being open minded in resolving new requirements for the VLTI. Operation is well integrated in the Paranal Observatory, both concerning data flow and staffing, and the control system allows VLTI to be operated by a single operator and a staff astronomer. Although the main problems currently causing technical downtime are not caused by the control system, there is some way to go before VLTI and its control system can be considered to be as reliable, as robust and have a technical downtime as low as the VLT UTs. Further challenges lie ahead when the complexity will increase with addition of new subsystems and functionalities.

7. ACKNOWLEDGEMENTS

The VLTI is being designed and built by the VLTI group, lead by Andreas Glindemann, of the ESO telescope division. The assembly, integration and commissioning at Paranal is coordinated under supervision of Philippe Gitton and Markus Schoeller. The control software described in this paper is based on the work done by the VLT software group headed by Gianni Raffi. The TPOINT and IPHASE packages were developed by Pat Wallace. The Interferometric Supervisor Software has been implemented by Jürgen Ott and René Rollfinke of 4D Engineering GmbH. Finally we would like to acknowledge the many years of dedicated work by Bertrand Koehler and Frederic Derie who made VLTI happen.

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