27th April 1990

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

The ALEPH Slow Control System

Abstract

The slow control system for the Aleph experiment at LEP is described. This system controls and monitors the operating conditions of the detectors and their "life support" systems. Novel features include extensive use of relational databases to describe the configuration of the detector systems and an interactive graphical status display. The slow control system proved to be reliable during the first data-taking run of Aleph in autumn 1989.

Paper presented at the Computing in High Energy Physics Conference, Santa Fe, New Mexico, USA, April 1990.

THE ALEPH SLOW CONTROL SYSTEM

T. Charity, J-M. Maugain, W. von Rüden and S. Wheeler
EF Division, CERN, CH-1211 Geneva 23, Switzerland.

J. Thomas

Max Planck Institut, Föhringer Ring 6, D-8000 Munich 40, West Germany.

ABSTRACT

The slow control system for the Aleph experiment at LEP is described. This system controls and monitors the operating conditions of the detectors and their "life support" systems. Novel features include extensive use of relational databases to describe the configuration of the detector systems, and an interactive graphical status display. The slow control system proved to be reliable during the first data-taking run of Aleph in autumn 1989.

INTRODUCTION

Aleph is one of the four large High-Energy Physics experiments running at the LEP electron-positron collider at CERN. The structure of the detector is described elsewhere [1]. The detector is composed of some ten sub-detectors and has several thousand operational parameters which have to be set and monitored in order to ensure that the detector is in the correct state for data-taking. These include quantities such as high and low voltages, temperatures and gas pressures. The Aleph detector is located in a cavern 160 metres underground whereas the control room in which the experiment operators work, is located in one of the surface buildings. In order to ensure smooth running conditions a highly versatile and relatively low-cost means of remote monitoring and control has been installed. The role of this "slow control system" is to monitor the experimental conditions locally and generate alarms in the control room when faults are detected. Operators alerted by the alarm signals rectify the fault either manually or remotely via a computer. The system is also used for the routine set-up of operating conditions for example high voltages, general monitoring and logging of operating conditions. Since the quantities to be monitored vary only on a timescale of seconds the control system need not have a very fast response. However, it must be reliable. The slow control system is implemented in a number of distinct parts which are listed below:

1. Independent control and monitoring programs for each sub-detector run on VAX computers configured in a VAX "cluster". These maintain displays of the currently monitored status of the equipment, show alarms, allow operators to control equipment and log slow control information to storage media.
2. All the sub-detector slow control programs communicate with their equipment via a single slow control "server" program running on a dedicated 3100 VAX workstation in the cluster. The slow control server is the only program in the cluster which communicates directly with the microprocessor system (outlined below) which monitors and controls the equipment. An interactive graphical status display showing the layout and status of the slow control system is also implemented on this workstation.
3. Low-level monitoring and control functions are performed by programs running in a distributed system of microprocessors attached to the sub-detector hardware. They are capable of understanding, executing and replying to simple commands sent to them from the VAX server program. Commands to stop and start monitor-

- ing are available as well as ones to read and change the status of attached equipment. The programs also send unsolicited messages to the VAX server when faults are detected.
4. Networks are used for communication between the slow control server and the microprocessors. The microprocessors are connected to a number of UTI-NET local area networks and the VAX cluster to Ethernet. Ethernet-UTI-NET gateways have been installed to allow communication between the two different networks.
 5. A large relational database describing the correspondence between the physical detector and the slow control system has been implemented on the VAX cluster. It is used extensively by the server to translate requests coming from application programs given in terms of the detector ("high-level" commands) into commands which will be understood by the microprocessor programs ("low-level" commands).

Figure 1: Slow Control Architecture.

The connectivity and essential elements of the slow control system are illustrated in figure 1. The lower third of the diagram shows two members of the VAX cluster. On the right is the dedicated workstation on which the slow control server program runs. On the left is another member of the cluster on which a sub-detector application program is shown running. The application program and server communicate via messages. The server exchanges messages with the microprocessor system shown in the centre of the diagram via Ethernet. The Ethernet-UTI-NET gateway converts the messages it receives to the correct format and sends them either to the correct microprocessor station (shown as MAC-64 stations on the diagram) or to the server's workstation. When a microprocessor receives a command it interprets it and performs the necessary action on the connected equipment shown in the top third of the diagram. A Fastbus power supply is shown as a typical example of the kind of equipment which is monitored and controlled by this system. The power supply is switched on if the microprocessor receives a command to pulse the DC_ON line and switched off if the DC_OFF line is pulsed. The power supply can be inhibited by setting a level on the AC_INHIBIT line. The status of the supply is read from the STATUS line.

THE MICROPROCESSOR SYSTEM

Low-level monitoring and control functions are carried out by programs running in distributed Motorola M6809 processors housed in MAC-64 (Monitoring And Control) stations based on the commercial G-64 bus [2]. They provide an integrated system with local processing capability to which equipment is directly connected. They are able to communicate over a local area network, UTI-NET [3]. Each station consists of a double height Europa chassis which contains the following system cards: - A Motorola 6809 processor card, paged memory, battery backed-up RAM and UTI-NET interface cards. In the main body of the crate there is room for 12 standard or custom designed G-64 type interface cards (lower level) as well as a second special card cage (upper level) to house adaptor cards. Their purpose is to adapt the signal type and level of the external equipment to the G-64 cards installed in the lower level and also provide card identification to allow automatic crate initialisation. A diagram of a typical MAC-64 crate is shown in figure 2.

Figure 2: A MAC-64 Crate.

A standard control and monitoring program has been written in Pascal to run under the Flex operating system in the 6809 microprocessors. Its purpose is to monitor all input values continuously and to check if they lie within pre-defined limits. If a value has exceeded its tolerance a warning message indicating the nature of the fault is generated and sent to the slow control server running on the VAX cluster. The program continues to send the warning message each monitoring cycle until it receives an acknowledgement from the server. This ensures that if the server is busy or unavailable for any reason the warning message will not be lost. Messages are also generated when the value previously out of tolerance returns within tolerance. The program understands a number of simple "low-level" commands. Commands are available to stop and start monitoring, to load monitoring parameters, to read currently monitored values and to control attached equipment. In order to ease maintenance, an attempt has been made to keep the program the same for all sub-detector applications, but some changes have had to be made to the program where special or unusual hardware has been implemented. The monitoring program has been installed in EPROM in each MAC-64 station so that the

program does not need to be downloaded after a station reset or a power failure. Similarly monitoring parameters previously downloaded to a station are saved in the battery backed-up RAM so that they are not lost in such circumstances.

The MAC-64 stations communicate with the server via a local area network. As already mentioned above we use UTI-NET which is a simple 128 kbit/s low-cost network developed at CERN. It is capable of interconnecting a wide range of intelligent devices for the purpose of data transfer. Up to 254 stations may be attached to a single segment. Although UTI-NET is a multi-master system, we use only one master (the slow control server) which runs on the central VAX and coordinates activity. This makes the system simpler.

The VAX cluster is connected to Ethernet [4]. In order that it may communicate with the MAC-64 system each UTI-NET segment has an Ethernet-UTI-NET gateway. This forms the link between Ethernet and UTI-NET and makes each UTI-NET segment look like a standard Ethernet node to the server running on the VAX cluster. The gateway box consists of a 19" chassis with a 5-slot VME bus and a 4-slot G-64 bus. Two VME cards, a VIP processor [5] with Ethernet* and an intelligent UTI-NET card [3] form the gateway. The G-64 bus is used for a "Head-End Unit" [3] which provides a clock for the UTI-NET segment and optionally for UTI-NET monitoring cards. A diagram of a typical gateway is shown in figure 3.

Figure 3: A Gateway.

The gateway software is written in C and runs on the 68010 microprocessor under the OS-9 operating system. Its role is to synchronise the transfer of messages between the two data networks which have very different physical characteristics. The program is loaded on resetting the system from files residing on the VAX cluster known as "network disks" [6].

In case of problems it is possible to reset both the MAC-64 stations and gateways remotely from the control room using the Aleph safety system.

* both thin-wire and thick-wire

THE SLOW CONTROL SERVER

A single server program coordinates all communication between the sub-detector control-and-monitoring application programs and the MAC-64 system. It runs on a dedicated workstation in the VAX cluster. However it may be run on any other workstation if for any reason the usual one is unavailable. It performs a number of functions.

On startup it tries to contact all the microprocessors currently registered in the slow control database. It then waits for messages either sent to it from sub-detector applications (via the Aleph message system [7]) or from the microprocessors (via UTI-NET and Ethernet). When the server receives a message from an application program it checks the source of the message and the message syntax, sending it back if the sending program has an incorrect name or the command has an incorrect syntax. Once checked the messages are decoded where necessary into 'low-level' commands understood by the microprocessor programs using the database, buffered and then sent to the MAC-64 station.

The server receives two types of message from the microprocessor system. The first are synchronous replies to requests made by the server, the second are asynchronous alarm and warning messages. Once all the low-level commands corresponding to a request have completed (or have timed-out after retry) an acknowledgement is sent to the requesting program with a flag indicating whether or not the request was successfully executed. If status information was requested the server updates the relevant part of the database before sending the acknowledgement. It is up to the requesting program to read the status from the database once it has received the acknowledgement from the server.

When the server receives a warning message it sends an acknowledgement to the sending station to prevent the station from sending the message again. It then checks the database to see if there is a sub-detector application program interested in receiving the message and if that program is currently running somewhere on the cluster. If so it decodes the message using the database and sends it to the interested user.

In addition to the main functions described above, the server also makes regular checks to see which gateways are running in the system and which sub-detector applications are running, updating the database accordingly. It updates counters in the database which record the numbers of messages which have been sent to and from each MAC-64 station and the numbers of messages which have been sent between each sub-detector application and the server.

THE STATUS DISPLAY

A graphical status display showing the current status of the slow control system is implemented on a colour workstation in the VAX cluster. In addition to providing a graphical representation of the current status of the slow control system by changing the colour of objects on the screen, it allows inconsistencies in the slow control database to be spotted more easily. Since the amount of status information which can be displayed is very large, the display has been made interactive so that the status of a sub-system may be viewed in greater detail by selecting it from the main display using the workstation's mouse. The display program is driven by a graphical database which is derived from the slow control database using the Aleph graphics package [8]. The graphical database contains information on how to draw various slow control components and the layout of these components. The display obtains information about the status of the slow control from the database which is kept up-to-date by the server. Since the display obtains information about the layout of the slow control system from

the slow control database, updates are easily included by rebuilding the graphical database.

THE SLOW CONTROL DATABASE

A central element of the slow control system as already indicated above is a relational database which describes all aspects of the system. It is one sub-section of the Aleph online database which also contains descriptions of the Fastbus system and the readout configuration. The entity-relationship data model [9] is used in the design of all the databases. In such databases elements in a particular system are represented by tables. A particular instance of an element occupies a row in a table and each attribute which describes the element occupies a column. Furthermore, the description of each element may be supplemented by specifying its relationship with other tables in the database or in other databases. The advantage of this type of structure is that it avoids the need to repeat information unnecessarily, thus reducing the possibility of conflicting entries and enhancing the integrity of the data. Entity-relationship diagrams have been used during the design phase of the database and provide a convenient means of displaying the database structure as will be shown later.

The slow control database allows sub-detector application programs to construct operator interfaces in the form of menus, independent of the slow control hardware configuration and microprocessor software. Instead of accessing equipment by specifying microprocessor commands to be performed on particular channels in a microprocessor station, the user may specify meaningful "functions" to be performed on pieces of their equipment associated with different parts of the Aleph detector. Using information stored in the database the server can decode the function given in the "high-level request" into the necessary microprocessor commands ("low-level requests") and send them to the correct destination. The high-level commands provide a convenient and error-free method of issuing complex requests.

The slow control database is linked to the detector description database which is another sub-section of the Aleph online database system. The detector description is a hierarchical description of Aleph in terms of its sub-detectors and their sub-components. By specifying the name of a part of the Aleph detector in a high-level request it is possible to access more or less equipment associated with that sub-detector according to whether the name of the sub-detector or one of its sub-components is given. For example, the application program which controls the high voltage for the hadron calorimeter can switch off part of the detector using one simple command, identifying the region of the detector by its physical location. Conversely the database makes it possible to translate alarm messages originating from the microprocessor system into meaningful messages consisting of the name of the piece of equipment from which the fault originated and the address of the piece of detector with which the equipment is associated.

Message interpretation and translation is data-driven meaning that the action of the message interpretation program is controlled by the data it reads from the database. Therefore the action of a program can easily be changed by modifying the data which it reads. There is no need to change the program in any way. This means that it is very easy to extend the system to include extra devices by simply adding them to the database using the menu-driven database entry program. Another advantage of pre-defining all the data relating to a sub-detector slow control system is that the applications may then use the data that have been entered to construct menus and displays. Since the programs are then data-driven, few if any changes need to be made if equipment is removed, replaced or added to the system.

In addition to providing a means of translation between the microprocessor system and the detector description, the slow control database is used to check access rights to equipment registered in it. It is also used to store the current status of the equipment and of the microprocessor system. User-defined monitoring parameters are saved and subsequently downloaded to the microprocessors by the server.

The slow control database divides logically into several parts:

- A description of the slow control hardware layout consisting of the configuration of the networks and microprocessor stations, and the way equipment is physically attached to the microprocessor stations and logically (or physically) associated with the detector. This is essentially static and needs only to be modified when a hardware element is modified, added or removed. There is a special menu-driven program which is used for this purpose. An entity-relationship diagram describing the layout is shown in figure 4.

Figure 4: Entity-Relationship Diagram for Slow Control Layout Database. The entities are represented by rectangular boxes labelled with the name of the entity. Relationships are shown by an arrow connecting two entities. The double arrowheads show for instance that there are several gateways hosted by a single VAX. The bar near the double head indicates that there might be a VAX which hosts no gateways. There is no bar at the other end of the arrow indicating that all gateways must have a host VAX. Key entity attributes and relationships are marked with the symbol *. Their purpose is to allow entities in the system to be defined uniquely.

- Lists of functions that may be performed on equipment with rules describing which functions are valid for particular types of equipment. Additionally a list of low-level commands is defined with rules describing which commands can be performed on particular elements in the slow control system. The correspondence between low-level commands and functions is also given in order to allow the translation of high-level commands to low-level commands. This part of the

database is static and need only be changed when new functions or microprocessor commands are defined.

- The current status of the equipment. This is maintained automatically by the server and is updated by the server on request from a sub-detector application program. Downloaded monitoring constants are recorded as well as the last monitored status of the equipment.
- The current status of the slow control system. To provide the graphical status display with information, the status of the microprocessor monitoring programs is recorded. Also statistics relating to the numbers of messages sent and received by the microprocessors and between the sub-detector applications and server are kept.
- The desired monitoring parameters for all the equipment. This part of the database is maintained by the different sub-detector application programs. The information may also be updated by the dedicated database entry program mentioned above. The server uses information saved here to download the correct monitoring constants to the microprocessors.

Figure 5 shows how different programs running in the VAX environment access the slow control database.

Figure 5: VAX programs accessing the slow control database.

DATABASE IMPLEMENTATION

The tabular format used for the slow control and the other online databases is the same as that used in the commercial ORACLE database system [10] which runs on the VAX cluster. However, due to concern about the overhead when accessing the data through ORACLE, the database has also been implemented as a number of system-wide disk-based global sections [11]. These are disk files which contain data that can be brought into memory and made available to programs for manipulation. A copy of the global section in memory may be shared by several programs. The data are accessed by programs using VAX-FORTRAN STRUCTURE and RECORD statements. Various tools have been written for copying data between the ORACLE database and the global sections. ORACLE is used to back-up the global sections and also provides the possibility of changing the structure of the tables whilst maintaining all the existing data intact.

STATUS OF THE SYSTEM

The slow control system proved to be reliable during the first data-taking run of Aleph in the autumn of 1989. During this time three of the Aleph sub-detectors were using the system. These were the hadron calorimeter, the small angle tracking chamber and the inner tracking chamber. Three UTI-NET networks and 6 MAC-64 stations were used. The system was always available and in constant use apart from power failures and a number of scheduled stops to maintain hardware or software. The system has continued to run smoothly during the LEP shutdown in the first three months of 1990. Three new users joined the system during this time (time projection chamber (TPC), TPC gas system and the level 2 trigger). They had previously been using a prototype version of the system. This brings the total number of UTI-NET networks and gateways to 5 and the total number of MAC-64 stations to 21. There are now over 4000 connected channels. Two small users (level 1 trigger and the vertex detector) will join in the near future adding a further two MAC-64 stations. We have just begun a new LEP run and the system is working well; the response has not deteriorated with the addition of extra sub-detectors.

ACKNOWLEDGEMENTS

We would like to thank the Aleph collaboration for their help in the development of and contributions to the slow control system described in this paper. In particular we acknowledge the contributions of A.E. Ball and J. Zaslavsky in constructing the MAC-64 system and E. Murer for the commissioning of the gateway.

REFERENCES

- [1] "ALEPH - A Detector for Electron-Positron Annihilation at LEP", The ALEPH Collaboration, to be published in Nucl. Instr. Meth.
- [2] G-64 bus, GESPAC S.A. Geneva, Switzerland.
- [3] "The UTI-NET Book", A.K. Barlow et. al., CERN/SPS/ACC/Tech.Note/84-1.
- [4] Ethernet, A Local Area Network: Data Link Layer and Physical Layer Specifications, DEC, Intel and Xerox Corporations.
- [5] "VIP Manual", T. Charity et. al., Aleph Online Note, May 1988.
- [6] "The Integration of Multiple OS-9 stations with a VAX/VMS host via Ethernet", T. Charity, IEEE Trans. Nucl. Science **36** (1989) 1726-1729.
- [7] "Aleph Message System-AMS Manual", B.Jost, Aleph Online Note, Feb 1990.
- [8] "GPH-User Guide", A. Aimar et al., ALEPH 89-11, Jan 1989.
- [9] "The Entity-Relationship model - toward a unified view of data", P.P Chen, ACM transactions on database systems **1** (1976) 9-36.
- [10] ORACLE User Manual, available from the ORACLE Corp, 3000 Sand Hill Road, Menlo Park, California 94025, USA.
- [11] "Design and Implementation of a Database-driven DAQ System", A.Belk et al., presented at the International Workshop on Software Engineering, Artificial Intelligence and Expert Systems for High Energy and Nuclear Physics, Lyon, France, March 1990.

STATUS OF THE SYSTEM

The slow control system proved to be reliable during the first data-taking run of Aleph in the autumn of 1989. During this time three of the Aleph sub-detectors were using the system. These were the hadron calorimeter, the small angle tracking chamber and the inner tracking chamber. Three UTI-NET networks and 6 MAC-64 stations were used. The system was always available and in constant use apart from power failures and a number of scheduled stops to maintain hardware or software. The system has continued to run smoothly during the LEP shutdown in the first three months of 1990. Three new users joined the system during this time (time projection chamber (TPC), TPC gas system and the level 2 trigger). They had previously been using a prototype version of the system. This brings the total number of UTI-NET networks and gateways to 5 and the total number of MAC-64 stations to 21. There are now over 4000 connected channels. Two small users (level 1 trigger and the vertex detector) will join in the near future adding a further two MAC-64 stations. We have just begun a new LEP run and the system is working well; the response has not deteriorated with the addition of extra sub-detectors.

ACKNOWLEDGEMENTS

We would like to thank the Aleph collaboration for their help in the development of and contributions to the slow control system described in this paper. In particular we acknowledge the contributions of A.E. Ball and J. Zaslavsky in constructing the MAC-64 system and E. Murer for the commissioning of the gateway.

REFERENCES

- [1] "ALEPH - A Detector for Electron-Positron Annihilation at LEP", The ALEPH Collaboration, to be published in Nucl. Instr. Meth.
- [2] G-64 bus, GESPAC S.A. Geneva, Switzerland.
- [3] "The UTI-NET Book", A.K. Barlow et. al., CERN/SPS/ACC/Tech.Note/84-1.
- [4] Ethernet, A Local Area Network: Data Link Layer and Physical Layer Specifications, DEC, Intel and Xerox Corporations.
- [5] "VIP Manual", T. Charity et. al., Aleph Online Note, May 1988.
- [6] "The Integration of Multiple OS-9 stations with a VAX/VMS host via Ethernet", T. Charity, IEEE Trans. Nucl. Science 36 (1989) 1726-1729.
- [7] "Aleph Message System-AMS Manual", B.Jost, Aleph Online Note, Feb 1990.
- [8] "GPH-User Guide", A. Aimar et al., ALEPH 89-11, Jan 1989.
- [9] "The Entity-Relationship model - toward a unified view of data", P.P Chen, ACM transactions on database systems 1 (1976) 9-36.
- [10] ORACLE User Manual, available from the ORACLE Corp, 3000 Sand Hill Road, Menlo Park, California 94025, USA.
- [11] "The Design and Implementation of a Database for the ALEPH DAQ System", A.Belk et al., presented at the International Workshop on Software Engineering, Artificial Intelligence and Expert Systems for High Energy and Nuclear Physics, Lyon, France, March 1990.