THE DESIGN OF THE ALBA CONTROL SYSTEM: A COST-EFFECTIVE DISTRIBUTED HARDWARE AND SOFTWARE ARCHITECTURE

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Abstract

The control system of Alba [1,2] is highly distributed. The hardware infrastructure for the control system includes in the order of 350 racks, 17000 cables and 6300 equipments. More than 150 diskless industrial computers, distributed in the service area and 30 multicore servers in the data center, manage several thousands of process variables. In this environment, the software client server model, with fast and reliable communications, was imposed. Tango[3] plays an important role. It is a big success story of the Tango Collaboration, where a complete middleware schema is available "off the shelf". Moreover, Tango has been effectively complemented with Sardana SCADAs (Supervision Control And Data Acquisition) [4,5], a great development effort shared and used in several other institutes.

The whole installation has been coordinated from the beginning with a complete cabling and equipment database, where all the equipment, cables, connectors are described and inventoried [6,7]. The cabling database, or "ccdb" can be considered as the core of the installation.

This paper explains the design and the architecture of the control system, describes the tools and justifies the choices made. Finally, it presents and analyzes the figures regarding cost and performances.

INTRODUCTION

Alba is a third generation synchrotron located near Barcelona in Spain. The Installation of the Control System for the Accelerators finished at the end of 2010. The final functional tests took place during the first weeks of 2011, right before the commissioning of the Storage Ring (see Fig. 1), which started the 8th of March of 2011. Currently we are carrying out the final stages of the installation and commissioning of the seven Beamlines of the first phase.

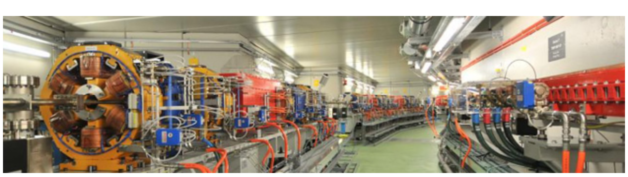

Figure 1: Picture of the Storage Ring (left) and Booster Accelerator (right) in the tunnel.

ARCHITECTURE AND PHILOSOPHY

Typically equipments are located in the tunnel and their controllers and electronics are installed in cabinets in the service area. This results in hardware being distributed all over the place. With this highly distributed installation, we needed as a general rule, distributed software, combined with a fast and robust fieldbus. On the other hand, although we have real time requirements, they are managed by the hardware avoiding the complexity and costs of managing a real time operating system such as RT Linux, VxWorks or RTEMS.

Ethernet as a Fieldbus

Ethernet is the standard for both control networks and fieldbuses. This makes the installation homogeneous, easy to maintain and guarantees a good longevity of the components. The network is physically configured as a star with two main switches having a backplane of 800Gbps each, and 20 Gbps links with the aggregators. It is logically organized in Virtual LANs (VLAN) for separating sectors and subsystems. There are independent VLANs for Safety, Diagnostics CCD cameras, Monitoring and Controls. In addition, every sector has a VLAN for Controls handling Beam Position Monitors, Power supplies, diagnostics, diskless computers, etc. The control room has workstations for running human machine interfaces all connected by Ethernet without any other application specific cable. The only exception is the Personnel Safety System (PSS), which has an independent Safety Bus, and an independent cabinet in the control Room.

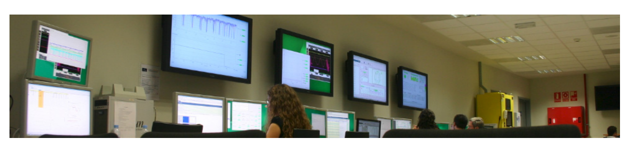

Figure 2: Picture of the Control room for the Accelerators.

The different pieces of software run on diskless compact PCI and industrial PCs, distributed in the service area with direct access to the hardware devices. The boot servers, archiving, Tango databases, CCD data acquisition and various other services, like electronic logbooks are centralized in the computing room (showed in the Fig. 2), where virtualization is broadly employed.

Tango as the Middleware

Tango was chosen among the three options we considered (Tango, EPICS [8], commercial SCADA). Although EPICS had clear advantages in several aspects, like a significantly wider catalogue of tools and a much wider community, Tango was preferred because of its

*On leave

newer technologies, object orientation, and definitely, because most members of the controls team at that time, having worked at the ESRF[9] before, were more familiar and in contact with the Tango community. Choosing Tango, we also disallowed having real-time and deterministic links in our middleware. We use a standard Linux distribution (currently openSUSE 11.1), as the main operating system for controls, with no real time extensions, which makes it cost-effective and easier to deploy and to maintain. Due to few very specific cards, a Windows installation is required in few computers (currently Windows XP), for which drivers were only available for this operating system. This is the case of the Low Level Regulation of the Radiofrequency cavities.

Human Machine Interfaces

Commercial SCADAs, have notoriously evolved over the last fifteen years. After the “crisis of the dot-com” at the beginning of the last decade, many companies were merged or absorbed in bigger ones. Nowadays, the number is still considerable, although, Wanderware and Siemens WinCC are the most popular. They used to be “monolithic” in the past, then they became distributed and today they turned out to be “Networked” in order to match recent requirements. They are integrating upwards with ERPs, and whereas in the past the challenge was to support a large variety of hardware, today the challenge is to ensure consistency of the information, atomic transactions and cyber security. Nevertheless, there are many examples of commercial SCADAs in particle accelerators, like “Global Screen” at Soleil [10] or PVSS (now absorbed by Siemens) at CERN [11] among others. However often in the industry, SCADAs cover the whole manufacturing process, whereas in scientific installations is often limited to human machine interfaces.

Commercial SCADAS did not fulfil our requirements. We needed an optimized access to hardware, a powerful and flexible environment for sequencing and macro execution, software synchronization, generic graphical interfaces, and access to save/restore facilities. For these reasons, we promoted a development of a scientific SCADA on top of Tango: Sardana [4]. Sardana also covers a complete framework for graphical interfaces: Taurus [12].

Real Time Hardware, non Deterministic Software

There are some cases, in which deterministic links are mandatory, such as synchronization or interlocks, where the system cannot afford having sporadic delays or loosing communications. We managed this determinism by suitable hardware, where dedicated systems handle the specific requirements.

The Equipment Protection System [EPS] [13] uses B&R hardware. It comprises about 50 PLCs and more than 100 distributed periphery supervising more than 7000 signals. Temperatures, water flows, valves, flow switches, compressed air, and vacuum valves, gauges and pumps are controlled by the EPS. Equipments inside the tunnel are integrated in shielded boxes with the remote periphery, guaranteeing a better modularity, shorter cables and facilitating the maintenance works.

All CPUs are intercommunicated by an independent deterministic network (Ethernet PowerLink), with a cycle time of 10 ms in most cases, ensuring a response time for interlocks of that order. Every experimental station has an independent EPS, communicating with the machine through hardwired digital inputs and outputs.

The Personnel Safety System is based on Pilz PLCs, SIL3 compatible following the norm IEC 61508. It is totally independent concerning hardware and software and relies on a dedicated safety bus with about 150 ms cycle time.

The timing system [14][15] is based on events and is built with hardware provided by MRF (MicroResearch Finland). It transmits the events using a clock of 125MHz synchronous with the RF frequency and a few picoseconds jitter. Each event receiver is configured to perform an action (i.e. activate pulse on an output) for a particular event code. There is one event generator and about 100 Event Receivers installed on the diskless compact PCI in the service area.

This infrastructure also handles the Fast Interlocks, redundant to the PLCs interlocks. This is an innovative system implemented by MRF upon Alba requirements. The system has a 8 nanosecond resolution providing time stamps and buffering of events, required for post-mortem analysis. In total 418 elements of the accelerator are synchronized and 49 fast interlocks are managed with a response time of about four microseconds.

AUTOMATIC CONFIGURATION AND CODE GENERATION

In order to facilitate the installation, and reduce maintenance time and costs, a central information repository has been setup: the equipment and cable database [6]. It is a relational database implemented on mysql, where types of equipments, cables and connectors are declared allowing later naming and managing instances of every item. This is the repository used for cabling installation, generating labels, cable check and validation. It has been extensively used during the preinstallation, and is constantly updated and kept up-to-date. Figure 3 shows a view of its web interface.

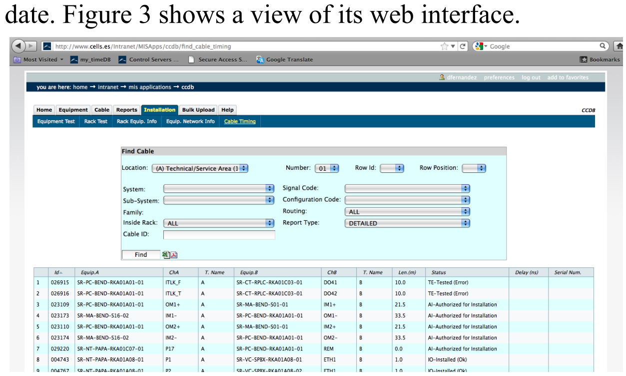

Figure 3: Snapshot of the web interface of the Equipment and Cabling database.

This is critical, since it is used for automatic software generation for PLCs, some Graphical interfaces and several files for configuration of network services, like DHCP, Radius and DNS.

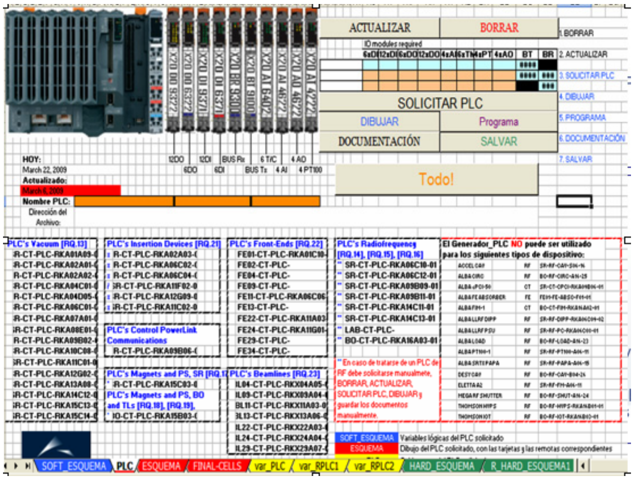

Figure 4: Excel application for EPS code generation.

Many components of programs running in the PLCs of the Equipment Protection System are generated automatically from the database. The huge effort done for keeping the database up-to-date and consistent pays back here, when software components are configured automatically, reducing the errors and increasing the efficiency. A Visual Basic Script running in excel generates another file containing the declaration of variables, data structures, software tasks, modbus mapping and documentation [16]. Figure 4 shows a view of the front page of the excel file. The Logic is still programmed manually due to the difficulty managing the large number of exceptions to the standard interlock rules. In addition, Tango attribute names and the expert GUIs are also generated from the controls equipment and cabling database.

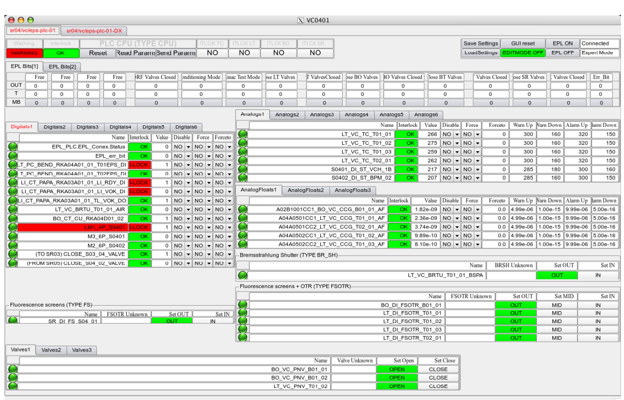

Figure 5: One of the expert GUIs of the EPS.

Important parts of the control system have also been configured from the cabling database. A python API [17] has been created for access to the ccdb, which provides functions for different purposes like extracting all information about equipments and connections between equipments. For example, for each vacuum device (gauge, pump or valve), all ports and the controller corresponding to that device, as well as the serial line and controls computer associated are extracted from the database. Other valuable pieces of information are also queried from the ccdb like the particular PLC which manages a given pressure interlock, the vacuum valves associated to that interlock, etc. Furthermore, the information available in the cabling database is used to extend the displays of the control system and allocate equipments in generic browsers. Figure 5 shows a view of a graphical user interface generated from the ccdb. The cabling API enables applications to sort and search by location of controllers or by location of the gauges connected to them. Also, graphical interfaces benefit from a centralized repository. For example a grid widget may query the cabling database to obtain the name of the instrument connected to a port, and show it as a label. Figure 6 shows the general user interface for vacuum controls, which uses few widgets automatically generated.

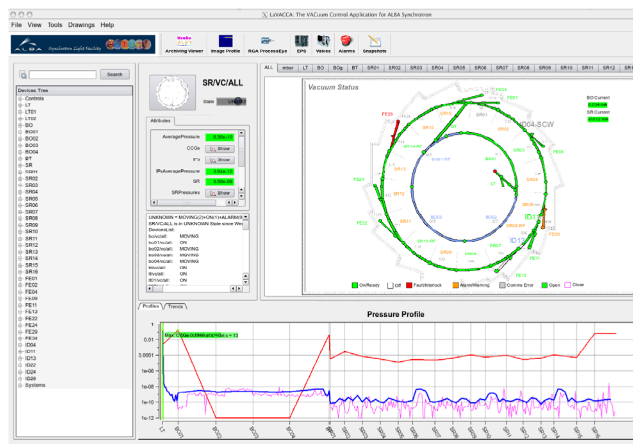

Figure 6: Snapshot of the vacuum control general graphical user interface (Vacca).

COSTS AND BENEFITS

We have considered price and functionality as important constraints for the design of the control systems Tango is cheap in terms of licences. It is distributed under the LGPL conditions and is free of charge. We have a similar case regarding the Operating Systems. Most distributions are free (openSUSE11.1). Windows workstations and servers cover less than 10% of the installation. Most programming is written in Python, for both control and data acquisition.

However, in several cases commercial packages like Matlab are needed. Packages for accelerator modeling like Matlab Middle Layer, need Matlab licences.

The choice of cPCI and Industrial PCs made the bill considerably cheaper compared to VME. We considered savings of at least 30%. ADLINK proved to be a cost-effective solution for cPCI crates, CPUs, data acquisition cards (DAQ) and Industrial PCs. ADCs are used in most places, whereas the use of voltage to frequency converters and counters cards is limited to few cases.

B&R PLCs proved to be a cost-effective solution. They are small powerful and above all, economical if we compare them with the market leaders such Siemens.

Concerning cabling, the fact of having a highly distributed architecture with electronics installed inside shielded boxes located in the tunnel, allowed shorter and cheaper cables. For a machine of 268m, we have an average length of 20 meters (36 if we consider only pure signal cables) with a final average cost of 120 Euros per cable. This is only a very rough estimation since for the price depends much on the type of cable. A high voltage cable for vacuum devices is much more expensive than a connection to a thermocouple, for example.

The having Ethernet as a fieldbus increased the cost of the network installation for the control system, but reduced significantly, the number of serial lines, which installation and commissioning is more time consuming, and we reduced significantly the number of cable types. CCD cameras, oscilloscopes, power supplies etc. are all controlled by Ethernet, reducing drastically the number and the length of coaxial cables.

CONCLUSION

The design of the control system had as main premises being functional and economic. From the beginning, a special attention was paid to cost and effectiveness. Choices such as Ethernet as a fieldbus proved to be correct since now (five years after the design of the control system of Alba) is the common choice. Currently during the commissioning, choices like a compact and economic PLC, or the absence of VME (extremely popular in this type of installations), are working very well. The tendency is to reduce the number of computers and rely even more on Ethernet.

Moreover, in order to make the installation and maintenance easier, a central repository (so called cabling database or "ccdb") was created. It soon turned out into a central repository for the whole installation, kept up-to-date and from where important pieces of software were automatically created. Some examples are the declaration of variables in PLCs, files for configuration of network services, dynamic attributes in device servers and components of graphical interfaces. This is a great tool for the maintenance since the information related to the installation is only in one place.

CONTRIBUTIONS

The whole controls, electronics, network system administration groups actively participated in the design, installation and tests of the control system. Among them, the person managing the installation of the Cabling Toni Camps and Beamline electronics engineering, Julio Lidón had a important role. Other persons which actively contributed are Zbigniew Reszela, Antonio Milán, Maciej Niegowski, Sergi Blanch, Jairo Moldes, Lothar Krause and Fulvio Becheri. Furthermore, the help of the Management Information System group, in particular, Oscar Sánchez, Isidre Costa, Alberto Nardella, Anne-Cecile Klora, Daniel Salvat and Valentí Prat, who developed and maintained the cabling database, the TimeDB and the Project Management system has been crucial. Furthermore we would like to thank the whole the ESRF in particular Emmanuel Taurel, Alejandro Homs, Vicente Rey and Laurent Claustre, who were involved in the early stages, and the other partners in the Tango Community, Nicolas Leclercq, Pascale Betinelli and Alain Buteau, from Soleil, Mark Heron from Diamond, and Timo Korhonen from SLS, who were always available to answer questions and give valuable advice.

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