STATUS OF THE LHC EXPERIMENTS’ CONTROL SYSTEMS

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Abstract

A new generation of large detectors is currently being built to run with CERN’s new accelerator, the Large Hadron Collider (LHC), which is due to start operations in 2007. The construction and operation of these experiments pose many technical and managerial problems and this applies also to the design, implementation and operation of their control systems. This paper will give an overview of the status of the controls for these experiments, the major issues to be addressed as well as some of the differences between the approaches adopted by the four LHC experiments.

INTRODUCTION

The LHC will be the most powerful instrument ever built to study particle physics. Due to switch on in 2007, the LHC will ultimately collide beams of protons at a centre of mass energy of 14 TeV. In order to capitalise on the opportunities offered at this new energy range, and in the search for new discoveries, a new generation of detectors is being built to operate with the LHC. In comparison with the last generation of detectors for collider physics at CERN, these new detectors are not only physically much larger, but also are being designed and constructed by much larger collaborations. In fact, in the two largest experiments, ATLAS and CMS, there are as many as 2000 collaborators in 150 institutes participating in each. Hence, the construction and operation of the LHC and of the four experiments will be very complex, both from a technical, and also from a managerial point of view. The development of the control systems for these detectors is likewise also a major challenge and the following sections will address how some of the technical challenges are being met.

MAJOR REQUIREMENTS

This section lists some of the major requirements concerning the detector controls. First of all, not only are the LHC detectors physically very large, they also have a very large number of controls channels (in the range of 5x10^5 to 5x10^6). This obviously imposes strict constraints on the controls and implies that it must be able to build large distributed control systems. Furthermore, as noted above, there are many sub-detector teams, spread across the world, involved in the development of the Detector Control Systems (DCS). These various developments must be made in such a way as that they can eventually be smoothly integrated together to form a complete and homogeneous DCS. This requires as much standardisation as possible as well as a common development strategy to be followed by all. Furthermore, the teams developing the sub-detector control systems will often not be experts in controls or in the technologies being used. Hence, the more user friendly and intuitive the tools to be used for the development of the control system can be made the easier this development will be.

Due to the nature of the experiment operations, the DCS must allow not only an integrated mode of operation but also a capability to allow partitioning of the system in a flexible way. This is to allow different sub-detectors/sub-systems to be operated independently and in parallel, e.g. for calibration or during shutdowns. In comparison to other control systems the DCS is required to control a wide diversity of equipment, including high and low voltage, temperature, pressure, gas equipment as well as cooling and ventilation equipment. Furthermore, the choice and placement of DCS equipment, especially readout units, is severely constrained by the harsh environment in the experiment caverns – high radiation and strong magnetic fields – which also limits access to equipment leading to the need for highly reliable systems.

APPROACH BEING ADOPTED

For all experiments a key element in the approach being adopted is the selection and use of standard tools and solutions. Some of these are provided centrally for all experiments and some are experiment-specific.

The development of each experiment’s control system is being done in a distributed manner. That is to say that each sub-detector is developing its part of the DCS. In some cases, the control system for a sub-detector is being developed by several teams at different locations, each responsible for a particular aspect, e.g. high voltage or cooling. Each experiment has a Controls Co-ordinator (CC) who is responsible for co-ordinating the various sub-detector developments as well as for addressing all central aspects/issues of the DCS, e.g. for selecting common technologies or for performing common developments. In addition, the CC has the overall responsibility for ensuring that the individual sub-detector developments are integrated to form a coherent DCS as well as interfacing to external systems. Finally, the CC is also the liaison to the Joint Controls Project (JCOP), which will be discussed later. In all experiments the CC leads a central team which helps to perform these necessary tasks.

Early in the design and development phase of the LHC experiments it was recognised that resources for controls, particularly from the side of CERN, would be very tight and also that the experiments’ DCSs had a certain amount of commonality. Therefore, in order to minimise the overall effort required for the development of the LHC experiments’ control systems, JCOP [1] was set-up in 1998 as a collaboration between CERN and the four LHC experiments. The aim of JCOP is to select and/or implement common solutions for the controls of the LHC experiments. The motivation for this was the realisation
that with the foreseen CERN staff reductions it would be essential to avoid duplicate developments and reduce the effort needed for support and maintenance. The mandate of this project is, therefore, ‘to develop a common framework and components for detector control of the LHC experiments and to define the long-term support’.

As such, JCOP provides a forum for discussing common issues and where appropriate for performing common developments of use in all the experiments. To date JCOP has organised three workshops, the aims of which were to understand better the requirements of each of the experiments, understand where common solution could be adopted and present and agree upon common technologies and solutions. Wherever possible commercial solutions are preferred in order to reduce the long-term maintenance. However, it is clear that commercial solutions are not always sufficient or even available and in such cases custom developments are made. In such cases, due consideration is given to the long-term maintenance of these.

**JCOP ACTIVITIES**

This section will describe some of the major activities performed by JCOP to-date. One of the first activities undertaken was that of the technology survey. The aim of this was to investigate whether commercial technologies such as Programmable Logic Controllers (PLCs), Supervisory Control And Data Acquisition (SCADA) systems and OLE for Process Control (OPC) would be suitable for use in the experiment DCSs. An important aspect of the evaluation of these technologies was their use in prototype applications.

PLC technology is widely used in industry and also for applications at CERN concerned with industrial processes, e.g. controls for cooling and ventilation, cryogenics and electrical distribution. CERN has selected two manufacturers of PLC equipment, Siemens and Schneider. Both were tested in prototype applications and found to be suitable for several aspects of the DCS, e.g. cooling and gas systems.

Although OPC is now a very well established industrial standard in the domain of process control, at the time JCOP first looked at it, it was only an emerging technology. The outcome of the evaluation was that although there were some limitations, essentially due to DCOM, OPC was found to be a suitable solution to integrate both commercial and custom devices with the supervision layer. By the end of the evaluation OPC was already becoming a de-facto standard. As well as being used for the connection to standard industrial devices such as fieldbus nodes and PLCs, OPC is also being used for the connection to High Energy Physics (HEP) devices such as high and low voltage power supplies, e.g. from CAEN, WIENER and ISEG. These companies have developed their own OPC servers on the recommendation of, and with the support of, JCOP.

For the evaluation of SCADA technology JCOP invested a considerable amount of time and effort. This activity was started in 1997 and was a follow on to the previous evaluations of EPICS and TIS4000 (a commercial version of EPICS). The investigation of SCADA technology was performed in multiple stages. The first step was to survey the market to understand what products existed and what their general capabilities were. On the basis of the detailed technical documentation provided, as well as visits to the companies, a short-list of the more promising products was selected for more detailed evaluation. For each of these products an evaluation license was obtained and ‘hands on’ evaluation of each tool was made. The results of these evaluations were presented to the second JCOP workshop following which the LHC experiments approved the principle of using a SCADA tool as a basic component of the DCS. In order to comply with the CERN purchasing rules a formal tender process was initiated and the product Prozeßvisualisierungs- und Steuerungs-system (PVSS II) from the Austrian company ETM [2] was selected based on a set of detailed criteria. The selection process and the experience gained so far with PVSS II are detailed in [3]. Major reasons for this choice were; device orientation, scalability, openness and flexibility of both the product and the company.

So far in this section a number of JCOP-selected and supported tools have been discussed. In order to provide these in a directly usable fashion for the sub-detector teams, i.e. customised to their needs, and to reduce the overall development effort, a JCOP Framework (FW) [6] is being developed. The FW is an integrated set of guidelines and tools to ease the development of control system applications. The FW is intended to include, as far as possible, all guidelines, templates, standard elements and functions required to achieve a homogeneous control system and to reduce the development effort as much as possible. Furthermore, the FW is intended to hide the complexities of the underlying tools to reduce the knowledge required by a typical developer of the controls application and hence allow for quicker development of applications in an intuitive manner.

In order to look at general aspects of the design of the FW, and of the DCS in general, an Architectural Working Group (AWG) was established. The work of the AWG was not performed in a purely academic way, but rather taking into account a number of constraints that were already known at the time, e.g. the use of PLCs, the use of PVSS, etc, as well as the experience gained in the development and operation of the LEP experiment control systems. The goal of the working group was to deal with detailed design issues which would be faced during the development of the FW. These issues included naming, system modelling, hierarchical control and partitioning, use of Finite State Machines (FSMs), access control, alarm handling, configuration and persistency, interfacing to external system, software versioning and diagnostics. The outcome of these discussions was summarised in the Framework Design Proposal [4].

From the software point of view, a hierarchical, tree-like, structure was defined by the AWG to represent the
structure of sub-detectors, sub-systems and hardware components. This hierarchy allows a high degree of independence between components, for concurrent use during integration, test or calibration phases, but it also allows integrated control, both automated and user-driven, during physics data-taking. This tree is composed of two types of nodes: Device Units (DUs) which are capable of monitoring and controlling the equipment to which they correspond and Control Units (CU) which can monitor and control the sub-tree below them, i.e., they model the behaviour and the interactions between components. Figure 1 shows the hierarchical architecture of the system. In this hierarchy “commands” flow down and “status and alarm information” flow up.

![Hierarchical Modelling](image)

Figure 1: Hierarchical Modelling

The implementation strategy of this modelling involves the use of the chosen SCADA system, PVSS, and a HEP-developed FSM toolkit, SMI++ [5]. PVSS provides the connection to the hardware and the modelling of the DUs based on the PVSS scripting capability. It also provides the HMI for both the configuration and operation of the hierarchy. However, PVSS does not provide for FSM modelling and hence SMI++ was chosen to provide this functionality as it allows for the design and implementation of hierarchies of FSMs working in parallel. SMI++ also provides for rule-based automation and error-recovery. There is a very close integration of these two products and the implementation benefits from the strengths of both products.

Another important aspect of the AWG design was to allow for flexible partitioning. Partitioning is the capability of monitoring and/or controlling a part of the system, a sub-system, independently and concurrently with the others in order to allow for tests, calibration, etc. Each CU knows how to partition its children. Excluding a child from the hierarchy implies that its state is not taken into account any more by the parent in its decision making process, that the parent will not send commands to it and that the owner operator releases ownership so that another operator can work with it. It was felt that excluding completely a part of the tree was not flexible enough on its own, so other partial partitioning modes were defined in addition to give extra flexibility. These will not be detailed here but are described in [4].

Figure 2 gives an overview of the JCOP FW. As can be seen, the FW in principle covers all levels down to the connection to the hardware. However, as there is only limited commonality in front-ends between the four experiments, the majority of the FW is provided at the supervisory level. Nevertheless, connection of other front-ends, and integration with the FW, is possible via one of a number of interfaces (OPC, PVSS Communications, the CERN-developed DIM or DIP protocols).

![JCOP Framework](image)

Figure 2: JCOP Framework

The FW provides a number of components which can be divided into two main categories; devices and tools. In terms of devices there are already a number of standard HEP items provided, including CAEN and ISEG High Voltage Power Supplies, Wiener Low Voltage Power Supplies and Fan Trays, the ATLAS ELMB (see later) and an accelerator data server. In addition, there is a set of standard configuration panels and standard script libraries to ease the implementation of non-FW devices. In the category of tools, there is the integration of the chosen FSM toolkit, an external alarm server, an integration of DIM as a driver, the hierarchical modelling tool, a mass configuration tool, an enhanced trending tool and an exception handling mechanism. Other devices and tools will be added as and when necessary following the priorities and milestones defined by the LHC experiments and according to the available resources. For instance the issues of interfacing to a configuration database and data storage and retrieval, i.e. interfacing to the conditions database and long-term storage, are being addressed and prototypes being developed.

Two other major activities of JCOP are the design and development of the 21 sub-detector Gas Control Systems (GCSs) [7] and the four Detector Safety Systems (DSSs) [8]. Whereas JCOP is responsible for providing tools and components to be used by the experiments to develop their DCSs via the FW, for the GCSs and DSSs JCOP is responsible for the complete applications. In order to minimise both the development and maintenance effort, both sets of systems will be based on generic frameworks and standard commercial hardware (PLCs and PVSS).

**EXPERIMENT SPECIFICS AND STATUS**

**ALICE**

The approach adopted by ALICE is that of trying to achieve as much standardisation as possible [9]. Due to
changing Controls Co-ordinators this effort started quite late and therefore many decisions regarding low level technology had already taken place. As a result, it is necessary to deal with a multitude of different readout mechanisms. Thus, to achieve the maximum commonality the requirements of the various sub-detectors are being collected via User Requirements Documents (URDs) and analysed. Where it has been too late to recommend common solutions, as with the monitoring and control of the Front-End Electronics (FEE), effort is being put into achieving a common integration mechanism to the supervisory layer. When considering the different types of systems, e.g. high and low voltage, FEE, cooling, etc., for the 18 sub-detectors this leads potentially to the need for about 110 different readout slices. By following the strategy described above this has been reduced to 10 common and 15 specific slices. The central team is working actively with the sub-detectors in the design, implementation and testing of these common solutions. In addition, the central team will be providing a General Purpose Monitoring System (GPMS) for a range of analog signals, e.g. temperatures, pressures, magnetic field strength. The GPMS will be based on the use of the ATLAS Embedded Local Monitoring Board (ELMB) – described below.

There is a large variation in the status of the controls activities between the 18 sub-detectors. On the one-hand there is one sub-detector with a fully working control system for a subset of the equipment which also includes the implementation of the FSM behaviour. On the other hand there are a number of sub-detectors which are still in the process of deciding between various technologies for their systems and this is especially true for high and low voltage.

**ATLAS**

The ATLAS central team has taken what could be described as a bottom-up approach, i.e. the front-end issues were tackled first. As such, the main emphasis of the work has been to develop a multi-purpose readout device to be used by all sub-detectors. The main requirements for such a device were high channel density, low cost, radiation tolerance and the ability to function in a high magnetic field.

As no commercial devices meet these requirements the ATLAS central DCS team designed and developed the ELMB (shown mounted on its mother board in Figure 3). This provides flexible I/O functions:

- multiplexed ADC, 16 bit, 64 channels with signal adaptation
- 8 input, 8 output and 8 definable digital I/O ports
- SPI bus
- low power consumption, opto-isolated
- add-ons: DAC, 12 bit, 16-64 channels; interlock facility

In addition, it is radiation tolerant for usage in the cavern outside of the calorimeter (0.5 Gy and 3*10¹⁰ neutrons per year) and is able to operate in a field of 1.5 Tesla. Finally, it supports remote diagnostics, loading of S/W and Single Event Error (SEE) detection and recovery. The final production run of 10000 units is underway with each ELMB costing less than SFr. 100.

![Figure 3: The ELMB on its Motherboard](image)

Thanks to this development a high degree of homogeneity has been achieved for the front-end. Also the connection to PVSS has been standardized by developing an OPC server. The back-end relies fully on PVSS and the components provided by JCOP. ATLAS has decided to keep the DAQ and the DCS independent. However, in order to enable coherent operation for data taking, a software package for the interaction between the two systems has been developed [11].

All sub-detectors have been using the ELMB and PVSS for their prototype and test beam work. They are now in the process of designing their final controls layout using the components described in this paper. During 2004 the integration of several sub-detectors will be exercised in two installations in an integrated fashion.

**CMS**

The architecture of the CMS experiment controls is divided into two domains, Run Control System (RCS) and Detector Controls (DCS). The first is responsible for configuring and operating the data-taking sessions, taking care of the electronics equipment directly involved in the flow of physics data; in particular the front-end readout electronics and the trigger and data acquisition systems.

The DCS is responsible for the setup, monitoring and protection of the detector, as well as for all systems associated to its operation (power supplies, cooling systems, gas systems, environment measurements, etc.). The DCS systems are based on industry standards and commercial hardware devices supervised by software tools developed by JCOP on top of PVSS. This guarantees uniformity and reliability and makes the long-term support and maintenance easier and less expensive. Experience in the use of the JCOP tools in a test-beam environment is being acquired.

It must be born in mind that configuring and operating the readout and data acquisition systems is highly dependent on CMS-specific hardware solutions, dictated by the specifics of the sub-detectors and their harsh radiation environment. Detector testing and calibration imply specific control and data acquisition capabilities...
LHCb

The emphasis of the approach of LHCb has been to achieve a completely integrated controls system [12]. As such, there is no distinction made between DCS and control of the DAQ as in the other LHC experiments. LHCb aims to have a single coherent Experiment Control System (ECS), which as can be seen in Figure 4 below, covers all aspects of control. Hence, there is no distinct DCS team, but rather an integrated on-line team.

CONCLUSION

It can be seen that the experiments have all adopted differing approaches overall to their controls. However, as a result of the collaboration through JCOP the experiments have been able to benefit from the complementary nature of these approaches and will all profit from the work performed through JCOP. Although in general the controls applications have yet to be written, much progress has been made in selecting common hardware and in developing a number of common tools and components. This will significantly ease the development of the production systems over the next couple of years in time for the start-up of the LHC.

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