

HIERARCHICAL CONTROL FOR THE ATLAS EXPERIMENT

A. Barriuso Poy^{a,*}, H. Burckhart^a, L. Carminati^c, J. Cook^a, V. Filimonov^b,
V. Khomutnikov^b, Y. Ryabov^b, F. Varela^a

^aCERN, Geneva, Switzerland, ^bPNPI, St. Petersburg, Russia,

^cINFN, Milan, Italy, ^{*}also URV, Tarragona, Spain.

ABSTRACT

The ATLAS experiment is composed of a set of sub-detectors which have differing requirements for operation. The task of the Detector Control System is to enable the coherent and safe operation of the experiment. In order to provide the required functionality, the Back-End of the control system is hierarchically organized, using a Finite State Machine approach. This paper presents the overall architecture and the standardized interfaces used to represent the sub-detectors, sub-systems and hardware components that constitute the hierarchical experiment control system.

1. INTRODUCTION

ATLAS [1] is a general-purpose particle detector designed to study p-p collisions at the Large Hadron Collider (LHC) at CERN, which will start operation in 2007. ATLAS will be the largest particle detector ever built, distributed over a cylindrical volume of 42 m length and 11 m radius. It is composed of three detector systems, the tracker, the calorimeter and the muon system. These are divided into 9 different specialized sub-detectors that perform different tasks such as track reconstruction and particle identification.

The Detector Control System (DCS) [2] supervises the hardware in the experiment set-up including all the detector services (e.g. high voltage, cooling) and the common experimental infrastructure (e.g. racks, environmental conditions). DCS also serves as interface to external systems such as the CERN technical services (e.g. electricity, ventilation) and most notably to the LHC accelerator (e.g. for beam conditions and backgrounds). The DCS consists of a distributed Back-End (BE) running on PCs and of the Front-End (FE) instrumentation.

The associated data volume to be treated by DCS is large because of the very many complex systems that form the detector. In total, around 200.000 channels will be supervised by the DCS. The magnitude of ATLAS, in terms of system complexity and collaboration effort, suggests a hierarchical structure as the natural way to organize the detector. Thus, the BE is organized in a tree like structure, segmented into sub-detectors, systems, sub-systems, etc. The hierarchical control and operation of the different sub-detectors will be performed by means of Finite State Machines (FSMs), which will handle the states and transitions of the different parts of the detector.

This paper discusses in detail the hierarchical control in ATLAS. Section 2 discusses the organization of the DCS BE. Section 3 introduces the FSM, the main tool for the implementation of the full control hierarchy. The architecture of the BE, specifying all the different constituent parts and their functions, is presented in Section 4. The interfaces defining the interaction between the modules of the architecture are explained in Section 5. The ATLAS standards applied for the implementation of the hierarchy are presented in Section 6. Finally, a prototype implementation of an envisaged hierarchy is discussed in Section 7.

2. ORGANIZATION OF THE ATLAS BACK-END

During the operation of the ATLAS detector many complex systems have to collaborate, and to face this complexity, the adopted solution is modularity [3]. This is carried out by means of FSMs that break down a complex system into discrete pieces – which then only communicate with one another through standardized interfaces within a standardized architecture.

The different systems that form a detector, such as high-voltage, low-voltage, cooling, etc, are normally produced by different teams using highly specific equipment, and therefore, the result is often heterogeneous. One way to manage this complexity is to reduce the number of distinct elements. In ATLAS, this is done in two different ways:

- Firstly, the software elements use the Joint Controls Project (JCOP) [4] framework as much as possible.
- Secondly, the distinct elements in ATLAS are reduced by grouping elements into a smaller number of sub-systems. The dynamic behaviour of this grouping is described by means of the FSM.

During the design phase, the ATLAS DCS has been decomposed into modules. This division into modules involves a partition of information into *visible design rules* and *hidden design parameters*. The visible design rules consist of three parts:

1. The *architecture* specifies the different constituent parts and their functions.
2. The *interfaces* define how modules interact with each other and externally with the person in charge of the operation of the experiment.
3. The *standards* offer ATLAS guidelines for the implementation of the control hierarchy (e.g. naming conventions).

These visible design rules must be chosen such that they do not have a negative impact on functionality or performance. They need to be widely shared throughout the ATLAS community and also must not constrain the evolution of the ATLAS DCS during the long lifetime of the detector (up to 20 years). Hence, these rules must be flexible and continue to be applicable in the case that the BE or FE systems evolve. In contrast, the hidden design parameters, which are the encapsulation of specific information of a certain module, do not need to be communicated beyond the boundaries of the module. In the literature regarding modular systems [5] the set of architecture, interfaces and standards is known as *modularization*.

In the next sections, the FSM, the architecture, interfaces and standards used during the building of the BE of ATLAS DCS are presented.

3. FINITE STATE MACHINE

The commercial Supervisory Control And Data Acquisition (SCADA) package PVSS-II [6] has been chosen by JCOP at CERN to implement the BE system of the four LHC experiments.

The FSM tool forms part of a software framework developed in the context of JCOP and it is based on both PVSS-II and SMI++ (State Management Interface) [7]. SMI++ is a tool for developing control systems and it is based on the concept of FSM. Complex systems can be broken down into simple FSM units that are hierarchically controlled by other FSMs. The detector can be decomposed and described in terms of SMI++ objects, which behave as FSMs. These objects can represent device entities, like a pump or a high-voltage crate, or logical groups of such devices, like a sub-detector or a gas system. Each object can automatically take decisions based on changes in its own internal status and in those of other components in the hierarchy [8].

4. ARCHITECTURE

The BE system is organized in three functional horizontal layers [2] and in all of them, FSM engines run to ensure a coherent operation of the whole (see Figure 1).

In the top layer, there will be a Global Control Station (GCS) which is in charge of the overall operation of the detector. It provides high level monitoring and control of all sub-detectors, while data processing and command execution are handled at the lower levels. The GCS will be able to access all stations in the hierarchy.

The Sub-detector Control Stations (SCSs) form the middle level of the hierarchy. Each sub-detector has its own station and an additional one will exist to handle the Common Infrastructure Controls (CIC). The SCS allows the full local operation of the sub-detector by means of dedicated graphical interfaces. At this level in the hierarchy, the connection with the Data Acquisition (DAQ) system takes place in order to ensure that detector operation and physics data taking are synchronized.

The bottom level of the hierarchy is made up of the Local Control Stations (LCSs), which handle the low level monitoring and control of instrumentation and services belonging to the sub-detector. The LCSs execute the commands received from the SCS in the layer above, but may also trigger predefined actions autonomously if required.

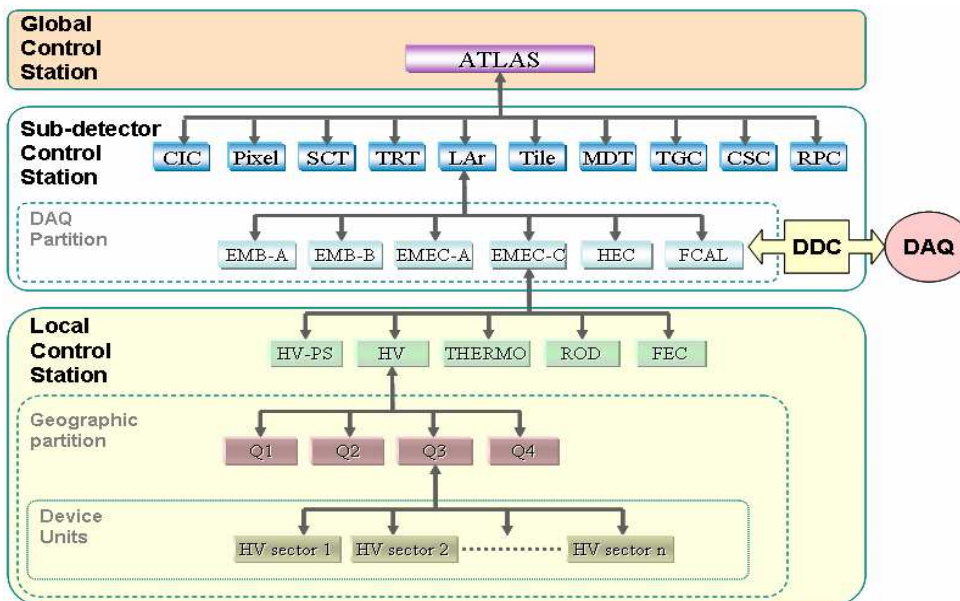


Figure 1: DCS BE Architecture

The implementation of the FSM hierarchy goes across the three functional layers of stations as shown in Figure 1. While creating the hierarchy, the designer must decide its *granularity*. This granularity defines the boundaries of the hierarchy. The information located below these boundaries is encapsulated and not visible from the FSM. At this point, one has to find out the structure of encapsulation which will yield the best system decomposition. The goal is to find the modularization that minimizes interdependences and most cleanly decomposes the system. An example of the High Voltage (HV) LCS for the Liquid Argon (LAr) Calorimeter can be seen in Figure 2.

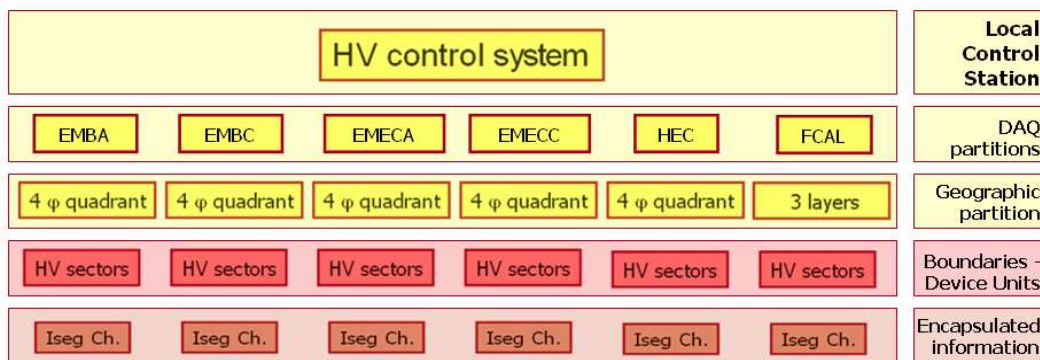


Figure 2: HV organization for the LAr calorimeter

The full set-up for the HV system in LAr is made up of more than 5000 channels. The channel level is not modelled in the FSM since the selected granularity has been a HV sector, which is a physical part of the detector using a group of channels. However, detailed information about the channels will be accessible from a user interface for experts. The reasons to select this boundary has been: a) too fine a granularity increases the connections between the FSM and the SCADA system, which may overload the processors, b) too coarse a granularity would accumulate too much information in a single entity, making it difficult to define its functioning state, c) the HV sectors are the smallest entities where commands have to be sent from levels above, and d), the behaviour of a HV sector is well defined based on the state of a group of channels.

The next level up divides the detector geographically into quadrants. The idea here is to divide geographically LAr in a common way for all the systems (e.g. HV, LV) that form a certain region (e.g. a barrel) of the calorimeter. Hence, all LAr systems will also use quadrants to organize their FSMs.

During operation DCS will receive commands from DAQ, and for this reason a DAQ layer is introduced. The HV system is divided such that it maps to the partitions of DAQ.

5. INTERFACES

The DCS BE will be geographically distributed over three different areas between the surface and underground locations and is estimated to contain around 100 stations in total. The flow of information between all these machines depends on many different interfaces using several communication protocols. In this section, three key interfaces for the hierarchical control in ATLAS are introduced: the interface DAQ-DCS, the internal interface between the different FSMs running on the hierarchy, and the human-machine interface.

Interface DCS-DAQ

The hierarchy is sub-divided according to the DAQ partitions which are based on the TTC (Timing, Trigger and Control) zones [9]. These allow the timing and trigger signals to be distributed to the readout electronics for data taking. Thus, following this segmentation, at a certain level of the hierarchy the DCS organization is a reflection of the DAQ partitions (see Figure 1). At this level the synchronization of both systems is accomplished by means of DAQ-DCS Communication (DDC) software package [10]. This package provides:

- Bi-directional data exchange
- Transfer of DCS alert messages to DAQ
- Transfer of DAQ control commands to DCS with feedback on their execution

FSM Internal Interfaces

The FSM tool is used to model devices and sub-system behaviour, to automate operations and to attempt recovery from error conditions. All this functionality is based on SMI++, a FSM toolkit independent of PVSS-II. The SMI++ objects can run in a variety of platforms, all communication being handled transparently by the underlying Distributed Information Management package (DIM) [7]. The FSM engine is interfaced with PVSS-II in order to extend the functionality of the SCADA system.

User Interface Prototype for the GCS

The GCS is in charge of the high level monitoring and control of ATLAS, i.e. presenting a general view of the condition of the detector to the operator. Figure 3 shows a prototype which was developed in order to have a single user interface allowing navigation through all the different levels of the FSM hierarchy presented in Figure 1. In this way, when a problem arises, the operator is able to access any single module within the full hierarchy of ATLAS. The interface displays the detector in two different views, a geographical view and a system view.

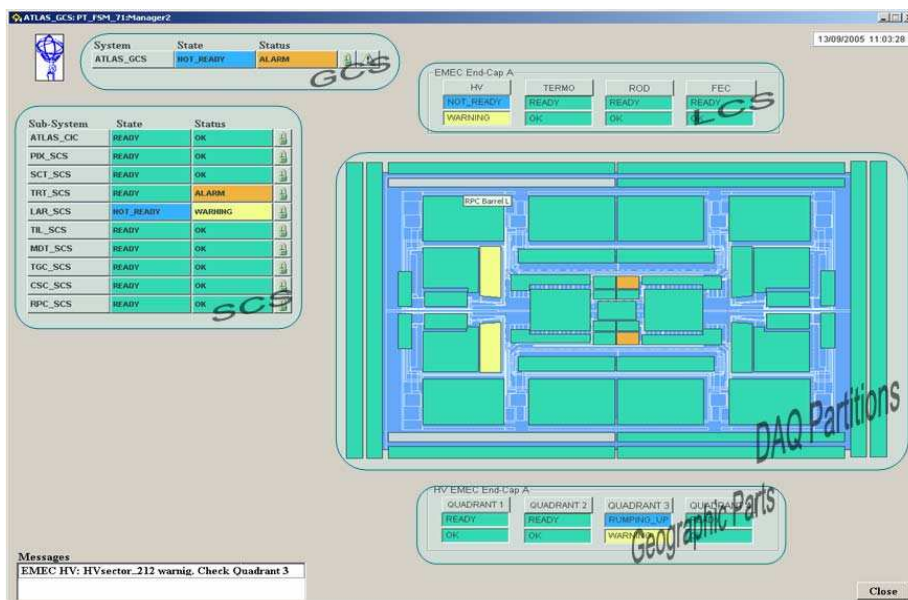


Figure 3: User Interface Prototype.

This first prototype uses a standard FSM user interface where the actual conditions of the parent node (GCS) and its children (SCSs) are shown. In addition, the same interface presents a schema of the whole detector divided into DAQ partitions and the connections to their respective FSM nodes. When an error occurs in any zone, the operator can open sub-modules that show the different systems and sub-systems belonging to the zone. In this way, one finds out exactly where the problem is and may then act accordingly. The same procedure can also be applied at the SCS level.

6. STANDARDS

In order to homogenize the BE control hierarchy of ATLAS a set of rules and conventions have been defined, an important example being “STATE” and “STATUS”. These are two aspects that work in parallel and provide all the necessary information about the behaviour of any system at any level in the hierarchy (see Figure 3). The STATE defines the “operational mode of the system” and the STATUS gives more details about “how well the system is working” (i.e. it warns about the presence of errors). The main reasons these two information elements are provided at each level of the hierarchy are the following:

- Information about the operational mode of a complex system or a group of systems is not lost when an error triggers. For instance, a HV system is in RAMPING_UP state and this process may take several minutes to finish. If in the meantime an error occurs it can be propagated up by means of the STATUS while keeping the same STATE. In addition, the two aspects define more accurately the behaviour for each level on the hierarchy.
- Complex systems can be supervised “more in detail”, e.g. an error may be treated differently depending on the operational mode of the system. As an example, depending on whether the STATE is ON or OFF, different severities can be attributed or different actions triggered.

7. PROTOTYPE IMPLEMENTATION

The performance of the FSM tools in the proposed organization, in terms of number of modules and levels of the hierarchy, has been investigated. In order to study the behaviour of a real set-up, a SCS was developed. Below the SCS, twelve LCSs running on different PCs, were created. In each LCS, a three-level FSM tree was implemented, where each node had three children. On the bottom level, different quantities of modules defining hardware components were used in order to run several tests. The largest set-up contained more than 10.000 modules, which is a factor three more than expected for a sub-detector. Several tests were carried out, such as forcing changes in all the modules at the same time with a certain rate, or checking the propagation time from the bottom to the SCS level after a change of state. The results of the test show that the proposed standards and organization have a performance that meets the requirements of the operation of the DCS.

8. CONCLUSIONS

The organization of the supervisory level of the ATLAS DCS has been presented. Due to the complexity and size of the detector, a hierarchical organization which follows the natural segmentation of the detector into smaller sub-systems, has been chosen. This hierarchy, as well as the behaviour of its different components are modelled using a FSM toolkit. The granularity of the hierarchy and its internal interfaces have been investigated with the aim to optimize the overall system performance. The results of these investigations led to the definition of design rules. These rules provide the flexibility to take into account the experience that will be gained during operation over the lifetime of the experiment, as well as to allow for future evolution of the control system.

REFERENCES

- [1] ATLAS Collaboration, “ATLAS: Detector and Physics Performance Technical Design Report”, CERN/LHC/99-14, TDR 14 and 15, 1999
- [2] Boterenbrood H. et al., “Design and Implementation of the ATLAS Detector Control System”, IEEE Real Time Conference, Montreal, May 2003
- [3] Langlois, R., “Modularity in Technology and Organization”, Research Papers Network Institutional Theory, February 2000
- [4] <http://itco.web.cern.ch/itco/Projects-Services/JCOP/welcome.html>

- [5] Baldwin, C., Clark, K., “Managing in an Age of Modularity”, Harvard Business Review, 1997
- [6] <http://www.pvss.com/>
- [7] Franek, B., Gaspar, G., “SMI++ - Object Oriented Framework for Designing Control Systems for HEP Experiments”, CHEP 97, Berlin, Germany, April 1997
- [8] Gaspar, C., “Partitioning, Automation and Error Recovery in the Control and Monitoring System of an LHC Experiment”, CHEP 01, Beijing, September 2001
- [9] ATLAS Collaboration, “ATLAS: High Level Data Acquisition and Controls. Technical Design Report” CERN/LHCC/2003-022, June 2003
- [10] Khomutnikov, V., “ATLAS DAQ-DCS Communication Software, Users Guide”, June 2005
<http://atlas.web.cern.ch/Atlas/GROUPS/DAQTRIG/DCS/DDC/ddc.html>