OPERATIONAL EXPERIENCES WITH THE ALICE DETECTOR CONTROL SYSTEM

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Abstract

The first LHC run period, lasting 4 years brought exciting physics results and new insight into the mysteries of matter. One of the key components in these achievements was the detectors, which provided unprecedented amounts of data of the highest quality. The control systems, responsible for their smooth and safe operation, played a key role in this success.

The design of the ALICE Detector Control System (DCS) started more than 12 years ago, based on the experience gained with previous generations of the high energy physics experiments. High levels of standardization and pragmatic design led to a reliable and stable system, which allowed for efficient operation of the experiment.

In this presentation we summarize the overall architectural principles of the system together with the standardized components and procedures. The original expectations and plans are compared with the final design. Focus is given on the operational procedures, which evolved with time. We explain how a single operator can control and protect a complex device like ALICE, with millions of readout channels and several thousand control devices and boards.

INTRODUCTION

Based on the commercial SCADA system WINCC OA extended by the Joint Control Project (JCOP) Framework [1], the DCS of the ALICE experiment at CERN resembles the other control systems at CERN. However, the architecture of ALICE online and offline, the running mode of the experiment as well as the organization of the overall collaboration strongly affect the implementation of the DCS.

The DCS has been designed to provide an uninterrupted service, assuring the safe and reliable operation of the experiment. The core of the control system is autonomous and serves its purpose even in the absence of external systems and services (i.e. during network outage or external system maintenance). During the standard operation, the DCS interacts with several systems both internal and external to ALICE. It serves as an important communication exchange point, providing vital data for detector operation, physics analysis, and safety systems as well as for external services, including the LHC. In order to fulfil all the tasks, the operation of the ALICE DCS is almost uninterrupted since 2007, when the system started to serve ALICE.

THE DCS ARCHITECTURE

The core services of the DCS are implemented in WINCC OA environment and constitute the control layer of the DCS as shown in Fig. 1. More than 100 individual systems are connected to one central distributed system, sharing the control and data of ALICE. The granularity of the overall system reflects the internal structure of the ALICE detector. For each of the 18 ALICE subdetectors an autonomous control system has been deployed. Thanks to this separation, each subdetector can be controlled independently of the others. Additional WINCC OA systems provide services for trigger, environment, LHC interface, etc. Finally, a group of systems covers central DCS and coordination tasks.

One of the basic design principles, deployed in the early stages of the project, is the hierarchical approach. The different system parts were segmented into subsystems, having similar functionality. Typical examples of such subsystems are Low Voltage, High Voltage, Cooling, Front-End electronics, Gas, etc. Currently there are 100 subsystems defined in ALICE. For each subsystem a separate WINCC OA system has been created. The computing infrastructure of ALICE DCS follows this segmentation and provides one computer for each individual WINCC OA system. Only in exceptional cases, control of certain subsystems has been merged into one WINCC OA system, in order to optimize the resources. The DCS granularity provides system robustness, where most of the ALICE components can be operated in case of an individual subsystem failure. In addition, the chosen subdivision provides room for system expansions and guarantees its scaling.

The central distributed system provides all functionality for detector control. However, its operation requires detailed knowledge on detector architectures, operational modes, and cross-dependencies. The DCS control layer has been extended into the operation layer, based on the CERN FSM toolkit. Each controlled component is modelled as an FSM, with well-defined states and commands. Using the toolkit a strictly hierarchical tree-like structure has been created. In this hierarchy each parent node can send commands to its child nodes and read their status. The status of the top-level DCS node becomes READY if all children in the tree are READY

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and changes its state if any of the children leave the READY state. Single nodes can reflect the complex status of the whole experiment, covering the top level detector nodes, all subsystems, devices and channels. There are in total some 15 000 logical nodes with 10 000 leaves (channels) implemented in the ALICE DCS.

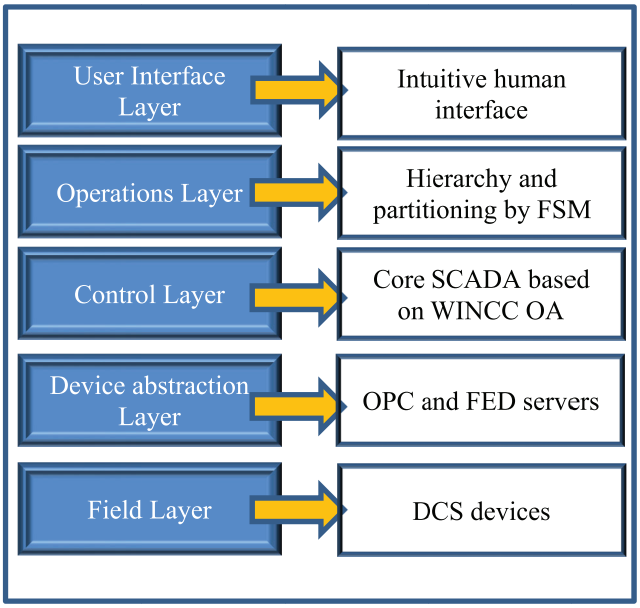

Figure 1: Layered architecture of ALICE DCS.

The partitioning mechanism, illustrated in Figure 2, is provided by the FSM toolkit and extends the flexibility of the system. The central operator can decide to exclude any part of the hierarchy and release its control to the expert, while keeping full control of the rest of the experiment. Excluded components do not contribute to the overall experiment state, which allows for parallel troubleshooting, tests, and development. The central alert system provided by the control layer keeps the operator aware of any anomalies, even for excluded devices.

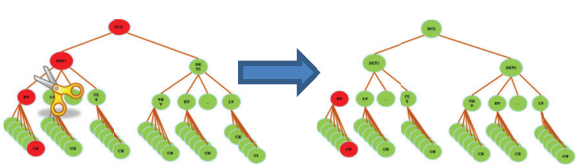

Figure 2: In the hierarchical system a single channel failure can propagate to top node and affect its state (left). Thanks to partitioning, the failing branch can be excluded from operation. In this mode, it will stop receiving commands from the parent nodes and reporting its status.

The User Interface layer simplifies the human interaction with the system using intuitive operational panels. An example of an operational panel is shown in Fig. 3. ll standard actions, even the complex ones like preparing the whole experiment for a run, can be invoked by a set of simple mouse clicks. The system automatically validates all actions and interlocks the operations which are not compatible with critical conditions. One example of vetoed operation could be an attempt to ramp up detectors if the beam background exceeds critical level.

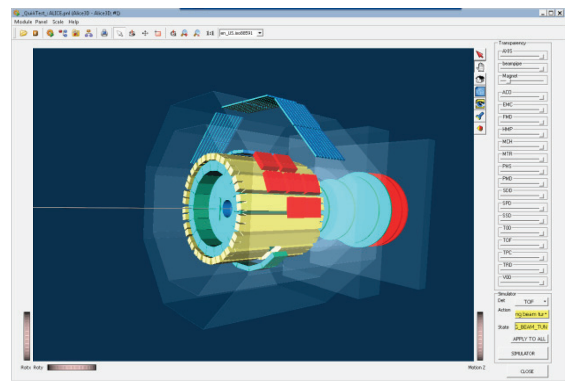

Figure 3: An example of operations panel implemented in the User Interface layer.

The DCS field layer consists of all hardware equipment required for experiment operation. Due to the diversity of detector technologies used in ALICE, standardization of the devices has reached its limits. It was still possible to reduce the number of different types of commonly used devices, such as power supplies, crates, and switches, however front-end electronics introduced a large variety of modules, communication buses (JTAG, Profibus, CanBus, RS232, Ethernet, etc.) and access methods. A new software-based device abstraction level fills the gap between the field and control layers. Its role is to hide the implementation details and provide a standardized communication interface. Wherever possible, devices are accessed via OPC servers; otherwise a so called FED (Front End Device) server technology is used [4]. The FED server provides device access using custom drivers, wrapped into a standardized framework based on the DIM protocol [3]. WINCC OA accesses all different kinds of front-end modules using the same DIM driver, included in the CERN JCOP framework. The FED server technology is also used to interface WINCC OA with commercial devices lacking the native OPC support by manufacturer.

CONTROL SYSTEM DEVELOPMENT AND INTEGRATION

The organization of the ALICE DCS project is largely decentralized. The different ALICE subdetectors are built in collaboration between 1200 physicists from 36 countries and 131 institutes. The institutes responsible for development of a given subdetector typically cover also the implementation of individual control systems. The task of the central coordination team, currently consisting of 7 people, is to provide the implementation guidelines,

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technical support and to supervise the integration. In addition to this, the central team provides the computing cluster, experiment infrastructure and central services such as database, network and access control, safety systems, etc.

Once developed in institutes external to CERN, the atomic control systems are transferred to a central computer cluster in ALICE. An autonomous group of computers is allocated to each detector and control systems are installed on them. The access control mechanism assures that the systems can be modified only by experts responsible for a given task and operated by trained shifters. Original expectations assumed that there will be 1 or at most 2 experts per detector and few shifters trained to operate each detector. The complexity of the system is reflected in the current situation, where 167 experts and 610 detector operators are registered. (This statistic does not take into account that about 30% of the operators are trained for several detectors, so they appear in several groups in parallel).

One of the characteristics of a large detector such as ALICE is that the final setup largely exceeds the capabilities of external test benches. The detector parts meet very often for the first time in the underground ALICE experimental hall. The control systems can be therefore fully tested only on the final production system, putting serious constraints on its design. The contingency created by computer cluster segmentation allows for addressing the performance problems. If needed, extra computers can be added to each subsystem, reaching the resource limits.

While scaling is in general a relatively simple technical problem, the integration of individual systems into one central service is a non-trivial task. Smooth common operation of different detectors can be achieved only if well-defined rules and guidelines have been followed through the whole development and implementation process. A set of integration tests is performed for each newly delivered system and common sessions are organized with all detectors. This is in fact a continuous process, carried out through the whole lifetime of ALICE. Each technical modification or evolution of operational modes triggers a need for a new set of integration tests.

SYSTEM DEPENDENCIES

Each detector control system can act autonomously, ensuring each detector control system is independent on the rest of ALICE. The WINCC OA based system is complemented by the Detector Safety System (DSS), providing protection mainly by hardwired interlocks.

At the detector level, a cross-subsystem dependency is a very common factor affecting the operation. Many detectors, for example, cannot ramp the high voltage, unless the low voltage system delivers nominal values. This in turn requires that cooling is operational and stable. In many cases a detector turn-on requires an execution of a multistep procedure which runs in loops. A front end chip cannot be configured unless it is powered. Once configured, the chip changes its operational characteristics and the low voltage has to be adjusted. Some of the detectors require efficient cooling for their front ends and the modules cannot be turned on without adequate cooling. The same modules can be however damaged by the cooling (frozen) if the chips are not powered and do not produce heat.

The importance of cross-subsystem dependencies can grow, if several detectors share infrastructure. To optimize the cost, some of the detectors share the cooling or expensive crates. In this configuration a detector expert cannot decide to turn off a subsystem without coordinating with other groups.

Even if achieved, the controls autonomy only guarantees that experts have full control of a subdetector under all conditions. It however does not assure the detector operation. To provide physics data, each detector has to rely on a number of external services, and additional cross-dependencies are introduced.

A typical operational feature is a dependency on central services. It is obvious that detectors cannot be operated without central infrastructure such as network, primary power and cooling etc. Data storage (fileservers or database), central configuration database, are not needed for safe operation of the detector, but are vital for physics data production. This field is covered by common solutions and tools, found in each high energy physics experiment.

Management of the cross-detector dependencies requires deep understanding of the whole experiment. For example, the increased accelerator background can be safely accepted by many detectors, while the same levels could have damaging effects on others. Counting rates of luminometers can decide whether the various gaseous detectors can be operated or have to be ramped down to their safe configuration. Conditions of one detector are therefore an important factor influencing the operation of other components. In addition, the readout of counting rates requires an operational Data Acquisition System (DAQ) and the DCS must be able to receive this information. In this way, the cross-system dependencies are introduced.

Finally, the DCS receives information from many external systems (LHC, magnet control, cooling, ventilation, electricity…) and provides feedback to them.

The coordination between different sub-systems and execution of complicated procedures cannot be covered by a central operator. All technical details are handled at the level of the FSM or embedded procedures. The operator issues a central command and all subdetectors and subsystems execute it, taking into account all dependencies.

The central distributed WINCC OA system allows for easy information sharing. In principle, each software module can read any information contained in the system. There are in total some 1 000 000 parameters supervised by the DCS. There is, however, an operational risk related to the linking of detector data. A failure of an individual system can easily lead to unexpected behaviour in a

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remote detector. For this reason a set of separate systems handling global parameters has been introduced. In this configuration, all critical parameters required for the operation are concentrated on separate systems. All detectors depending on this information subscribe to global parameters, instead of creating links to the information source. This concept simplifies the overall system management.

SYSTEM OPERATION

The primary role of the ALICE experiment at CERN is a study of ultrarelativistic heavy ion interactions. The proton collisions are important for detector calibration and first of all as a reference for physics analysis, however the operation of ALICE focuses mainly on short heavy ion runs provided by the LHC. In past years, the ion runs were scheduled towards the end of each year, before the annual CERN shutdown. ALICE participated in proton data taking; there was a small room for detector fine tuning and developments even during the operation with beams. Again, the FSM partitioning mechanism allowed to address this problem in a very elegant way; however it introduced a new level of complexity.

The LHC operation follows a standard cycle. The beams are first injected into the LHC and then accelerated to final energies. After necessary adjustments, collisions for physics are established. This part of the cycle is called "stable beams" and detectors can take data. During the data taking, all parameters are set to nominal values by the DCS. The beam adjustments and especially the beam injection can create a hazard for the detectors. To cope with the risk, outside of the stable beam periods, the detectors are put into so called SAFE condition. All critical parameters are set to values that can handle possible glitches and prevent the detector being damaged by the beams.

The operation with beams is not compatible with detector partitioning. Once a part of the detector is excluded from the hierarchy, it stops receiving commands from the central operator and does not report back the status. If the central operator executes a procedure to protect ALICE against risky beam conditions, the excluded parts will not receive this command and will not report back the possibly dangerous state. To overcome this problem, an independent mechanism has been introduced: dedicated procedures monitor all critical values and report back the status via communication channels independent of the FSM. The operator keeps an overview of the situation and can force the protective actions even to excluded parts. This mechanism can be used for all critical operation and is implemented for example for adjustments of the magnetic field of the central solenoid.

THE VALUE OF THE TRAINING

The DCS is typically controlled by one central operator. Each subdetector provides an on-call expert, who can be consulted or could intervene in case of problems. During operation with beams, the DCS shifts cover 24/7 operation. In the periods without the data taking, the DCS can operate in automatic mode, but for safety reasons most of the shifts are manned as well. In the period 2011-2013, 1800 shifts, each lasting 8 hours, were covered by central operators. In 2011, the central shifts were carried out by 80 different operators. In 2012/2013 this number raised to 100. In addition, the central DCS team provided a non-stop oncall service throughout the year.

The central shifters need to be trained for the operation. Training sessions are typically organized for groups of 5-6 people, but individual sessions with single trainees are not rare. Each shifter needs to pass a lecture, explaining all aspects of the ALICE DCS operation. The theory is then complemented by 3 training shifts in the experiment control rooms. During the last shift, the trainee is expected to operate the experiment.

Prior to the first shift, the trainee can enhance his/her skills on a hands-on setup. A simulator available to all shifters is installed in the DCS training centre and it mimics the real experiment operation. Finally, a set of guides covering the theory, the operation and troubleshooting ire all available for download on the DCS website. All last minute changes and exceptions are tracked in an operational TWiki and are consulted by the shifters at the beginning of the shift. The central DCS on call expert is in close contact with the shifters and provides any necessary support.

CONCLUSIONS

The first LHC run period stressed the need for stability and performance of the ALICE DCS. The uninterrupted operation of the control system significantly contributed to the success of the experiment. The lessons learned during the operation were implemented into procedures and tools which have increased the overall complexity of the system, whilst increasing redundancy and stability and reducing bad things

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