THE FIRST RUNNING PERIOD OF THE CMS DETECTOR CONTROLS SYSTEM - A SUCCESS STORY

F. Glege, O. Chaze, J. A. Coarasa, C. Deldicque, M. Dobson, A. Dupont, D. Gigi, R. Gomez-Reino,
C. Hartl, L. Masetti, F. Meijers, E. Meschi, S. Morovic, C. Nunez-Barranco-Fernandez, L. Orsini,
W. Ozga, A. Petrucci, G. Polese, A. Racz, H. Sakulin, C. Schwick, A. C. Spataru, C. Colin Wakefield,
P. Zejd, CERN, Geneva, Switzerland
U. Behrens, DESY, Hamburg, Germany
R. K. Mommsen, V. O'Dell, FNAL, Chicago, Illinois, USA
O. Raginel, F. Stoeckl, G. Bauer, C. Paus, K. Sumorok, MIT, Cambridge, Massachusetts, USA
S. Erhan, UCLA, Los Angeles, California, USA
J. Branson, S. Cittolin, A. Holzner, M. Pieri, M. Sani, UCSD, San Diego, California, USA

Abstract

The Detector Control System (DCS) of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) at CERN has been running since the first detector test in summer 2006. It has proven to be robust, efficient and easy to maintain. The efficiency of the system is close to 100% and thus maximizes the time for physics data taking. The challenges in the design of that system, however, were unprecedented due to the large size (millions of parameters to monitor) and its diversity. The CMS detector has been taking data from the autumn of 2009 until the beginning of 2013. During this period the CMS DCS had to show if it would meet the expectations and allow for an efficient running of the CMS detector.

In the following we will discuss the solutions applied to cope with those challenges, which also allowed for the good performance the CMS detector is showing since its start of data taking. The shortness required by this document, however, does not allow for an exhaustive presentation of the different mechanisms and thus they will only be sketched.

STARTING POINT

From previous (smaller) experiments at CERN we knew that a hierarchical controls system structure is advantageous for several aspects. (The details will be discussed later in this document.) We also knew that automation of controls helps to increase the efficiency. The automatic reaction to the accelerator status for instance maximizes the time available for physics data taking, since no time is lost on an operator decision/operation. The automatic error recovery avoids erroneous operator actions and ensures a fast reaction. Due to the complexity and size of the system it's not obvious for the operator to immediately know the nature of the problem and the most adapted remedy. It will usually take some time to get the information required to understand the problem and to decide on the action to be taken.

CHALLENGES

The challenges in building CMSs DCS were mainly its size and diversity. Millions of channels have to be monitored and hundreds of thousands controlled. Any wrong parameter value can have an impact on the physics data quality. The DCS needs to run 24/7 365 days a year and must be controllable by only one non expert person. A system failure during physics data taking might result in data loss. The controls data is distributed over hardware systems of different types, e.g. power supplies, temperature and other analogue values measuring devices, electronics crates, etc. . The hostile environment with areas of different radiation levels and the 4 Tesla magnetic field dictate the controls hardware choices. Not only is the type of parameters different per device type but also the means to communicate those to the controls system. The update rates vary from one parameter to another and so do the value ranges. Tera bytes of archived controls data have to be kept available and readable.

The developers are independent and distributed over teams from different detector parts. They have different technical backgrounds and cultures and the mean of steering is persuasion. The people might change and the different sub systems had different schedules.

The size of the final system in numbers:

- 3 million parameters
- 700.000 lines of code
- 35000 Finite State Machine (FSM) nodes
- 70 SCADA systems
- 70 PCs
- 50 DB schemas
- O(TB) of data in schemas

The running conditions were the following:

The CMS DCS was running ~27600 hours in central operator mode since autumn 2009. (~32400 in total up to now). The commissioning took ~3 month and the mean number of required expert interventions was ~1-2 per week.

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COPING WITH SIZE

The key to handling the large size of the project was factorization and templating. The CMS DCS system was sub divided into many small entities with equal behavior. Those entities and their behavior are modeled using the finite state machine toolkit SMI++. A behavior is only defined once and then instantiated. This approach allows for easily changing multiplicities and thus system size and decouples functionality and topology. The latter one is therefore defined external to the entities. This approach reduces the development to templates and a few instances are sufficient for simulating the whole system. Adding now the requirement of a single non expert user being able to control the whole system, a hierarchical structure has been defined. In our case the structure represents the detector structure. This enables non experts to understand the system status down to a certain level. A qualitative summary is passed to the parent at all level s leading to a simple reflection of the overall quality of the detector components and the experiment as a whole for what concerns the detector controls part. Commands are fanned out to the children allowing for simple controls of the overall system and detailed representation of possible complex parameterization of front end devices at the base of the hierarchy. This way the same system can be used for easy control by a non-expert of the whole system and expert interventions of specialists.

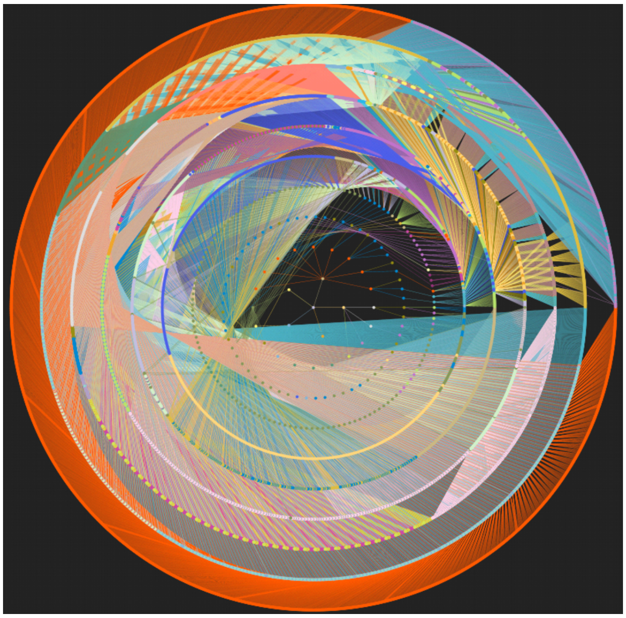

Figure 1: Structure of the CMS FSM hierarchy in a circular view.

HOMOGENIZING DIVERSITY

The Supervisory Controls and Data Acquisition (SCADA) software used in CMS is WinCC OpenArchitecture (WinCC OA) formerly known as Prozess Visualisierungs- und Steuerungssoftware (PVSS). The core of WinCC OA abstracts the controlled items to structures of values. Different applications called drivers map those numbers to the parameters of the very devices being controlled. Those drivers are available for different communication protocols. At CERN we decided to push the abstraction layer further down towards the front ends and chose OLE for process control (OPC) as a protocol for which the corresponding driver is included in WinCC OA. All hardware providers have therefore been asked to provide OPC servers as an interface to their systems. Whilst the idea was a good one, it turns out that the software expertise of hardware providers might be limited and developing an OPC server is a complex task.

Although the detectors of the CMS experiment are quite different one from another, the DCS hardware means used to control them are often similar or the same. A concept of reusable software components had already been introduced by the Joint COntrols Project (JCOP) framework, a toolkit based on WinCC OA for creating controls systems for high energy physics experiments. CMS took this further and identified common functionalities amongst the sub systems, which could use equal behavior implemented software wise, adapted to the very application by configuration. This replicates the concept already seen in the finite state machine hierarchy now applied on the WinCC OA side.

Another possibility for generalization lies in the computing infrastructure used for detector controls. To reduce the effort for setting up and maintaining PC hardware, CMS uses a standard PC configuration for all controls systems. To ensure those configurations staying the same, no user is allowed to access the computing systems directly. To allow for changes to the systems by the developers for maintenance, upgrades, etc. , a computing service like infrastructure has been set up. This service provides tools to target SVN versions of the software components to be deployed on the DCS computing nodes. Integrity checks avoid foreseeable errors in the application code before deployment. The detector expert gets feedback on the deployment process through on line tools. The latter ones also provide information about the status of the running applications and allow for basic operations like starting and stopping of processes. Access to logging and other information produced by the applications is also given.

ALWAYS AND NEVER

The CMS DCS has to run 24/7 365 days a year. Any interruption during physics data taking can limit the amount of data taken and thus decrease the efficiency of the experiment. Therefore possible sources for errors have to be either eliminated or contained. The unforeseeable, however will always occur and other means have to be put in place to minimize the impact of any system failure.

To respond to the latter, services in the CMS DCS which many or even all DCS nodes depend on had been identified and made redundant. To do so, the redundancy feature of WinCC OA was used, in which at least two PCs execute the same functionality. Each of the two redundant partners

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checks constantly the status of the other one and takes over in case the other one fails. The switch over is transparent to the rest of the system.

Through this mechanism system failures could be kept local and would not impact the whole controls system. Furthermore many system maintenance tasks can be executed in a transparent way, since the two redundant systems can be separated and worked on independently.

To profit even more from the advantages of redundant systems, the whole CMS DCS is currently being made redundant. To do so two identical PC clusters have been installed in distinct locations, depending on mostly different services like electricity, cooling and networking. The aim in doing so is also to eliminate the need for system interventions outside working hours and thus relief the support team.

LESS IS MORE

The millions of parameters of the CMS DCS are impossible to be supervised by an individual. First of all the sheer number value changes per time can't be followed. Furthermore there is nobody who has enough detailed knowledge of the system to know the meaning of each parameter and thus would be able to judge their correctness. Experience shows that most of the wrong actions are done by the operator and the system mostly reacts correctly. It's therefore desirable to automate the software system to the maximum and equip it with as much intelligence as possible to enable it to handle problems by itself: fast and correctly.

The primary mean to reduce the amount of information to be monitored has been discussed already and is given by the hierarchical summary of the information. However, still an overall detector expert would be needed to interpret the information, its severity, its impact on the rest of the system and the physics data taking and to know the most appropriate remedy. To allow for non-experts controlling the experiment, knowledge about the quality of the current state and possible automatic actions have been included in many nodes in the hierarchy. This renders the summarized information more intelligible and allows for fast safety related actions based on more complex information.

An alarm and help system has been set up. Every parameter can be attached to an alert, fired in case certain conditions assumed as good are left. Those alerts can be addressed to the detector expert only in case no impact on the current physics data taking is expected or to the central shifter in the opposite case. The central alarms are shown to the operator and point to a dedicated help, which the detector expert has assigned to this alert. The help will usually explain the nature of the problem and the remedy.

Those systems not only remove the need for specific detector knowledge of the operator but also ensures the fastest possible reply to problems popping up. In practice the operators were able to control the experiment after a one hour introduction to the system.

CONCLUSIONS

The CMS DCS represented a challenge mainly due to its unprecedented size. The key concepts of the system are factorization in a hierarchical structure of templated instances and synthesis of status information. Redundancy and the service like computing infrastructure ease the maintenance.

The above features helped to achieve an efficiency of the CMS DCS of close to 100%.

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