# DETECTOR CONTROL SYSTEM

H.J.Burckhart
CERN, Geneva, Switzerland

*Abstract:*

The importance of using a powerful Detector Control System (DCS) has much increased with the size and complexity of High Energy Physics detectors. The generation of detectors for the LHC experiments puts further requirements onto DCS due to the inaccessibility of the equipment and the hostile environment concerning radiation and magnetic field. Novel techniques such as fieldbuses for distributed input/output and Programmable Logic Controllers for closed loop control have to be employed. These represent the layer closest to the detector of a hierarchically organised multi-layer DCS. After having introduced the general concept of the DCS the paper will concentrate on hardware-related aspects and will stress the desirability of standardisation in the fields mentioned above.

## 1. MOTIVATION

The necessity of an overall DCS has arisen with the advent of the LEP experiments in the late 1980s. The experiments had become too big and too complex to be controlled manually. The experience gained is an important input to the design of the DCS for the LHC experiments.

Usually one operator supervises the whole experiment, normally a physicist of the collaboration. As he might not be working with the hardware of the detector at all, he might have only little knowledge in this area. But even a hardware expert will know in detail only the part of the detector, which he is involved in. Therefore the usage of DCS must be based on general common sense and must not presume much detailed knowledge. In fact this detailed knowledge about the operation of the different parts of the detector might even get lost over the years of running as experts will leave and new persons will join. However this knowledge can be preserved in procedures defined in DCS.

It is most obvious, that the earlier problems get detected, the lesser the consequences are they have and the easier they can be fixed. Therefore regular checking of the many hundred thousand parameters of a LHC detector is essential. The level of severity of problems together with the appropriate actions to take has to be defined by the experts and the possibility must exist that DCS shuts down *automatically* (parts of) the detector, i.e. without operator intervention.

The functionality described above was in general implemented in the Slow Controls Systems of the LEP experiments. However the DCS for LHC experiments should include further, more advanced features. Malfunctioning of a subsystem may result in a cascade of error messages and automatic actions. To find the *original* cause of the problem is sometimes far from trivial and may require the support of an artificial intelligence system. This may also give suggestions and advice to the operator how to react. Such a system may also learn about the normal operational behaviour of the detector and may be in position to give a forecast of the problems, which are about to come up. This may enable the operator to intervene and prevent the fault to develop or this information can be used to carry out preventive maintenance. Such a system may in the end even be able to solve problems autonomously.

## 2. SCOPE

A homogenous and coherent way of interaction has to be provided with all aspects of the experiment, namely the detector itself, the LHC accelerator, and the infrastructure and services.

### *2.1 Detector*

A LHC detector can be subdivided in a hierarchical way, the highest level consisting of the tracker, the calorimeter, the muon detector, and the trigger and data acquisition (DAQ) system. For DCS a further factorisation into "subdetectors" is appropriate. This is not only influenced by the different technologies used, but also by organisational questions. For example if different groups of institutes build the barrel and the end-cap of the electromagnetic calorimeter – even if the same technology is employed – it may be appropriate to define two independent subdetectors concerning DCS. The subdetectors themselves are composed of several levels of subsystems. Two possible examples for the hierarchical organisation of subdetectors are shown in Figure 1. This can.be done in many different ways and is completely at the discretion of the groups involved.

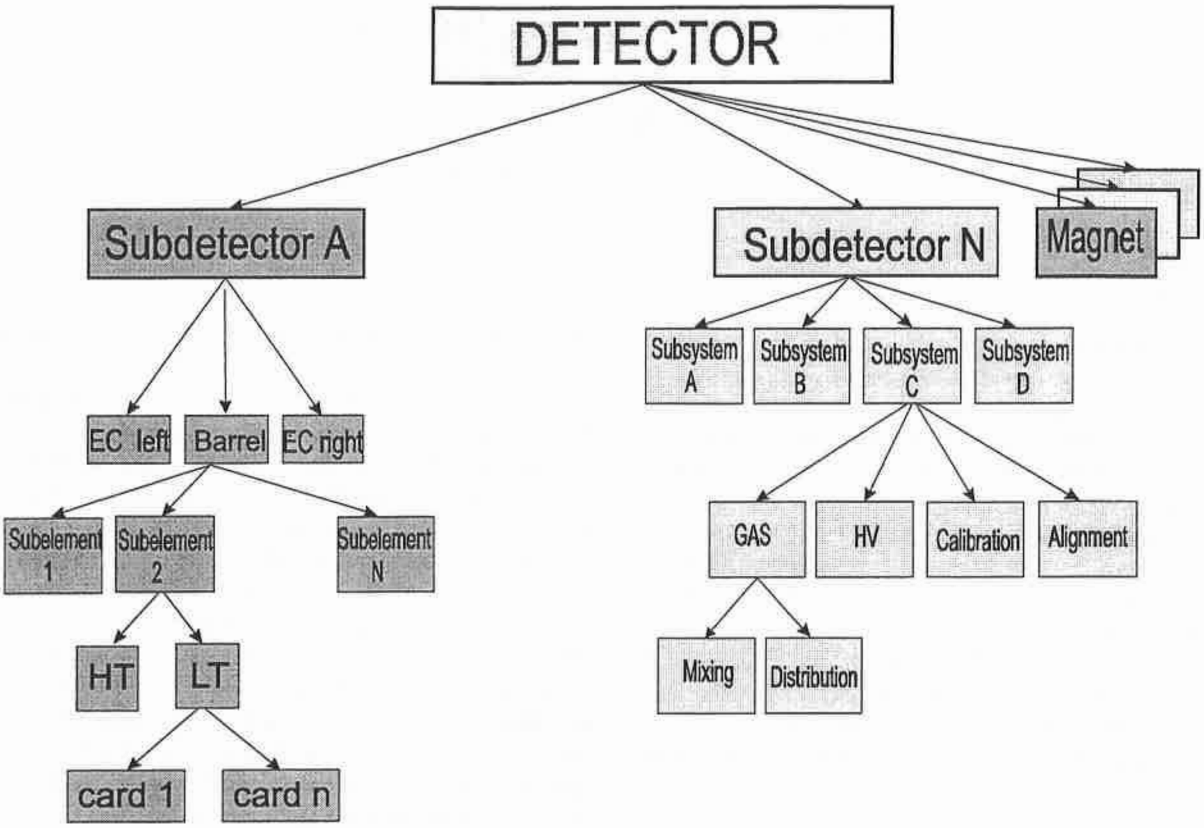


Figure1: Hierarchical organisation of subdetectors.

DCS should cover all interactions with all subdetectors, ranging from simple operator commands to very involved interactions executed by the subdetector expert. In all cases it has to be verified internally that the interaction requested is safe for the detector. The same procedures may be usable for different detectors and certainly the same type of hardware can be used in many places. This helps in standardisation between the different groups and is economic concerning resources and maintenance.

DAQ also connects to all subdetectors, as DCS does. The borderline between the two systems is naturally defined by the type of data involved. DAQ deals with all the aspects of physics events, like data flow and storage, quality monitoring and such like. These data are organised by event numbers. All other types of data, which are normally organised by a time stamp, are the domain of DCS. Quite intense interaction between the two systems will be needed. This consists of exchange of commands with the replies following and of status information in general. However DCS should operationally be completely independent from the DAQ system, because the latter is normally only running during physics data taking. In contrast DCS has to be operational all the time. In order to avoid negative interference, different communication paths to the detector should be used for both systems wherever possible. The split in two systems does not exclude that tools and services can be used in common. In the case, that the same function is provided by two different implementations, an interface between the two without loss of functionality must be available.

## *2.2 LHC Accelerator*

All interactions with the LHC accelerator should be channelled via DCS. As the detectors are the ultimate sensors for tuning LHC, information needs to be continuously exchanged about the instantaneous luminosity and the backgrounds. In fact all operational parameters of the accelerator, which might have an impact on the operation of the detector or on the subsequent physics analyses have to be available to DCS and must be logged. Also action requests like beam dump or injection inhibit should be transmitted via DCS. Another responsibility of DCS will be to measure integrated radiation doses in the different parts of the detector. As these services are also needed outside the data taking periods, they have to be provided by DCS and not by DAQ.

## *2.3 Services and Infrastructure*

There are various external systems the experiment has to communicate with. Examples for such systems are the cooling, ventilation and cryogenics plants. The state of them and even more importantly, early indications of problems have to be known. Interaction with the electricity distribution system may also be required. A special case presents the safety system. Information exchange with DCS is needed in both direction, but it should not be possible for DCS to act on the safety system in order not to disturb its operation. However early warnings about safety problems will enable DCS to take corrective actions or to shut down the problematic part of the detector. It is absolutely essential that the global safety status be presented to the operator at all times. DCS should act as user interface to this system.

In summary DCS is the mandatory tool for all actions the operator does and for all status and error reporting. DCS is not responsible for the security of the personal and for the ultimate safety of the equipment. The latter has to be guaranteed by hardwired interlocks and perhaps by local, stand-alone Programmable Logic Controllers (PLC).

## 3. REQUIREMENTS

In the following only the requirements, which are specific for our environment as compared to industrial controls will be discussed.

It has been shown that the detector is composed of many quasi-independent units. They all go through different phases like R&D, prototyping, pre-series production and tests, mass production, assembly, calibration, installation, and finally operation. Each phase includes controls needs. In fact the functions required increase from one phase to the next. In order to avoid that developments diverge for the different subdetectors, the relevant functions have to be made centrally available in time. In the end one just wants to combine the different control systems into a single one. Once the full detector is integrated one has from time to time operate its different components separately, e.g. for maintenance. Hence DCS needs the capability to work in two ways: in many small partitions and integrated as one overall system.

The existence of external systems, which have their own controls, and the independent DAQ system require, that DCS is open, which means that standard interfaces for communication are defined.

As an experiment is a research facility and is in constant evolution in contrast to a production plant, DCS has to be flexible and allow for frequent changes of the control procedures. These higher level operations must be decoupled from the basic low-level functions, which supervise the safe operation.

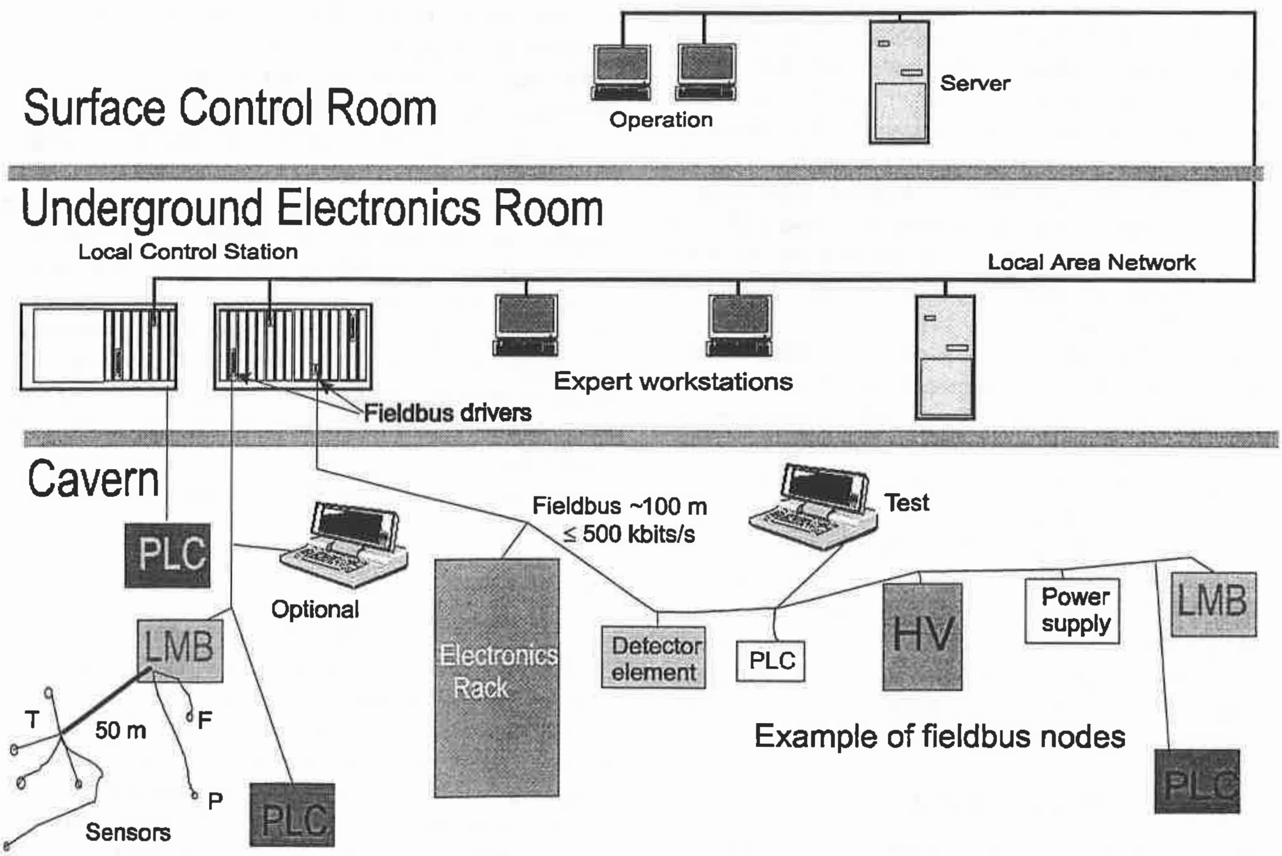


Figure 2: Architecture of DCS

A very special requirement on the hardware results from the hostile environment, in which the detector operates. The electronics situated in the experimental cavern has to tolerate radiation and magnetic fields. This implies also, that this part is not accessible during data taking and powerful remote diagnostic tools are required.

# 4. ARCHITECTURE

DCS will be hierarchically organised in layers as shown in Figure 2.

The top layer consists of operator and server workstations, which are situated in the main control room on the surface and in the accessible electronics rooms under ground. This layer implements the supervisor functions like alarm handling, data and incident logging, operator interface, etc.

In the next layer are the Local Control Stations (LCS). They supervise a subdetector or one of its subsystems in an autonomous way.

The next layer following consists of programmable front-end systems. They are geographically distributed in the cavern over typically 100 meters, according to the needs of the detector. The concept of the fieldbus, which interconnects nodes, is very suited for this purpose. There are different types of nodes. Commercial general-purpose nodes offer e.g. configurable analogue or digital input and output channels. Commercial devices like power supplies, cooling units etc. may comprise a fieldbus interface to a local micro-controller. Individual detector elements like tracking chambers may include in their dedicated front-end electronics a fieldbus node for local monitoring and control. Another possibility to implement robust local supervision is to use a PLC, in which a rather simple program regularly reads the inputs connected and executes the actions defined. This is ideal for closed loop control.

DCS will be organised in such a tree-like structure, which reflects well the organisation of the detector. Depending on the size and complexity of a subdetector or a subsystem one decides onto which controls level to map it. It is important to note that information flow is mainly vertical in the tree.

The boundary between the general DCS and the subdetector equipment is the LCS. It houses both standardised modules like a fieldbus interface and purpose-built connections to the detector. Diagnostic procedures are generally executed in the LCS, but during maintenance periods test equipment can be connected in the cavern.

# 5. FRONT END SYSTEM

Most of the front-end equipment will be installed in the cavern, giving rise to the following problems:

- Radiation tolerance
- Operation in a magnetic field
- Highly distributed I/O points
- Inaccessible during data taking

The radiation levels vary by many orders of magnitude from up to 100 kGy/year close to the interaction point and in the forward region down to 1 Gy/year in shielded areas. Concerning controls one can distinguish two categories. For the Inner Detector radiation hard electronics will be required. This will be part of the read-out electronics and will be designed using special technologies. Outside the calorimeter radiation tolerant electronics will be sufficient. For this electronics, which will be installed at accessible places, one should be able to use standard commercial components of the shelf (COTS). However some special care in the design has to be taken. Only selected components, with samples verified in radiation tests should be taken. The design should aim at higher performances than needed, i.e. using a 16-bit ADC when only 12 bits are needed, in order to allow for degradation due to radiation. For the same reason one should operate the components at lower parameters than specified. During operation one has regularly to check the integrity of memories. And finally one should foresee the possibility to exchange the electronics during the lifetime of the experiment. These preventive measures are still much cheaper than to design everything in a radiation hard technology.

The magnetic field in the cavern will vary in direction and magnitude from place to place and will reach values of a few hundred Gauss. Therefore electronic components like coils, chokes, transformers, and some types of DC/DC converters can not be used. Also power supplies may be sensitive to magnetic field. Therefore one should foresee to feed the electric power via cables.

The I/O points will be distributed over the whole volume of the detector. Cable length of some ten meters will suffice to connect sensors to I/O concentrator of typically some hundred channels. All this electronics is accessible only during periods without beam in the LHC accelerator.

The solutions to all these requirements are fieldbuses and PLCs.

## *5.1 Fieldbus*

A fieldbus is a simple cable bus, connecting "intelligent" nodes by using a well-defined protocol. The nodes usually contain a microprocessor. They can execute simple tasks like data conversion and reduction, error detection, etc. A big variety of fieldbuses is in use in industry. It ranges from simple cables reading out sensors up to the complexity of Local Area Networks. These fieldbuses are well supported by industry both in hardware (chip sets, ready made general-purpose nodes, measurement instruments) and in software (drivers, diagnostic and supervisor software). The fieldbuses differ in their technical characteristics like bandwidth, network topology, length, determinism, robustness, error handling, openness, redundancy, etc. An investigation in this field has been performed [1] and 3 fieldbuses are recommended for usage at CERN: CAN, Worldfip and Profibus. They cover all areas of applications needed.

### *5.2 PLC*

PLCs also cover a wide performance range. It starts from small controllers for closed loops with a few parameters and goes up to complex I/O systems of hundreds of channels. They usually have a simple program structure, i.e. one big loop, which gets executed in regular intervals, and the may have interrupt capabilities. As there is no operating system and no multi-tasking involved, they are very robust and are deterministic. However their possibilities and their flexibility is limited. They usually have a dedicated programming environment. Connection is provided via LAN and/or via a fieldbus. They are usually proprietary systems.

### *5.3 Applications*

Both fieldbus nodes and PLCs are very suited for distributed I/O concentrators. They can perform simple data processing and reduction. Also local, low-level control tasks are well within their capabilities. As powerful remote diagnostic tools exist, access is normally not required.

The usage of a fieldbus also helps standardisation. The definition of the electrical characteristics and of software protocols allows different types of nodes to reside on the same bus.

## 6. PRACTICAL WORK

A joint controls project (JCOP) [2] between the 4 LHC experiments and the CERN IT/CO group has been started. The aim is to use as much components as possible in common for the DCS of the 4 experiments. This should use the resources available in the most effective way, not only in the implementation phase, but also during exploitation. The system should be based on commercial products wherever possible. Dedicated interfacing to the individual DAQ systems, which will be different in the 4 experiments, will be needed. The interfacing to the external services will have to be done only once.

After the collection of the requirements, the high level architecture is being defined. In parallel a technology survey [3] has been carried out in order to investigate commercial control systems. An evaluation of the most promising supervisor systems has started. It will be carried out in 2 phases, first in the laboratory with devices supported by the product, and then in a subdetector project using also specific front-end electronics. Controls aspects of complete subsystems and devices like high voltage supplies, gas systems, and electronics crates and racks are also being studied.

Concerning hardware detailed work with the fieldbus CAN [4] and the software protocol CANopen has been carried out. A general-purpose analogue input device has been built and the performance and the radiation tolerance have been measured [5].

## 7. CONCLUSIONS

The LHC experiments will need a powerful control system. The tree-like organisation of the detector requires DCS to be structured in layers. For the lowest layer, which connects to the detector, fieldbuses and PLCs are very well suited. Emphasis should be put on the usage of commercial components, both hardware and software. This will help standardisation not only between the different subdetectors of one experiment, but also between the 4 LHC experiments and maybe the LHC accelerator.

## 8. REFERENCES


[1] G.Baribaud et al., "Recommendations for the use of fieldbuses at CERN", CERN ECP 96-11, June 1996, http://itcowww.cern.ch/fieldbus/report1.html

[2] http://itcowww.cern.ch/jcop/

[3] A.Daneels and W.Salter, "Technology Survey", http://itcowww.cern.ch/jcop/subprojects/TSurvey/

[4] CAN in Automation (CiA) Users and Manufacturers Group, http://www.can-cia.de/

[5] B.Hallgren and H.J.Burckhart, "Front-end I/O via CANbus of the ATLAS Detector Control System", these proceedings