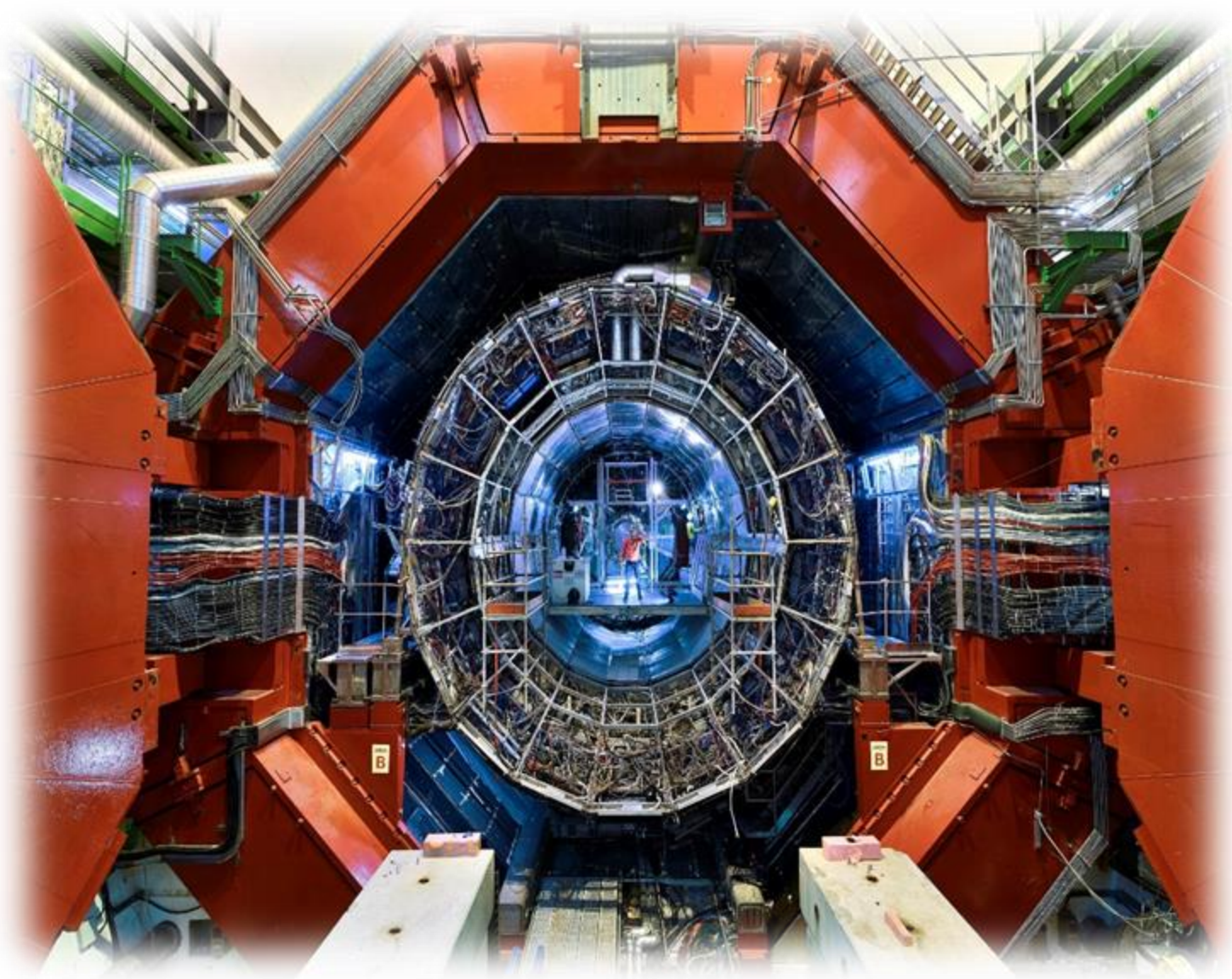




ALICE LHC IF Project: the WinCC OA System





Short Report
for the
CERN online educational
initiative experience
2020

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Scope of the document

The 2020 edition of the Summer Student Programme regularly offered by CERN was cancelled owing to the COVID-19 pandemic and an online version of this project took its place for this year: CERN managed, in fact, to adopt a distance-learning system in order to ensure the traditional summer activities by bringing them directly into each of the students' homes and starting what can be called the "2020 summer online educational initiative". My personal experience as a student of this programme is now coming to an end (Starting date: 29/06/2020. Scheduled end date: 25/09/2020) and this is a technical report on the work I have done in these past 13 weeks and serves as a way of demonstrating to the CERN Organization the knowledge and basic skills I have acquired by presenting and explaining the concepts I have learned in the first place.

Summary

ALICE LHC IF is a control software mainly developed in the SCADA environment of the WinCC OA System which provides communication channels between the systems of ALICE and LHC. ALICE is one of the four major experiments dislocated along the LHC and its function is to study heavy-ion physics by analyzing the products of the collision of heavy ions that impact against each other at velocities close to the speed of light. The WinCC OA software gives an efficient solution to the problem of managing, visualizing and controlling such amount of data produced by the experiment, improving and facilitating the daily activity of the ALICE LHC IF Project. This Short Report describes the above mentioned concepts reporting also the personal WinCC OA training experience obtained during the 2020 online educational initiative offered by CERN.

Contents

1	Introduction	5
2	ALICE LHC IF Project	6
2.1	Functionalities	7
2.2	Services	8
2.3	O^2 Computing System	8
3	Introduction to ALICE	9
3.1	The experiment	9
3.2	The problem of data management	10
4	WinCC OA System	11
4.1	Main properties	11
4.2	Working principle	11
4.3	An Event-Driven system	12
4.4	The human-machine interface	14
4.5	Personal experience	15
5	Conclusions	18
	References	19

Chapter 1

Introduction

Founded in 1954 in Geneva, the CERN laboratory has always conducted research on the basic constituents of matter, using accelerators to accelerate subatomic particles up to the speed of light in order to generate high-energy collisions, the effect of which can help researchers find the fundamental laws of nature. Such a noble goal can not be achieved without the collaboration of physicists and engineers from all over the world, in fact as one of Europe's first joint ventures, the Swiss center now has 23 member states and is involved in many international joint projects. This means that most of the physics research and discoveries that evolve from these projects are thanks to the efforts of many on a global scale. Following this open-mind mentality, CERN has offered its resources to anyone that can potentially provide a valid contribution to any running project and that is why it allows for university students from all over the world to take part in an on-site summer programme known as the "Summer Student Programme". This project started many years ago and has been very successful since, opening its doors to hundreds of international students that are given the opportunity of taking part in experiments conducted on the biggest accelerator ever built, a once in a lifetime experience that was this summer replaced by an online educational programme (due to the COVID-19 pandemic) and that I am extremely grateful to have been part of. Needless to say for health and safety reasons this year the students were unable to participate in this programme at the CERN Centre itself but were involved and enlightened through distance learning.

The project I was assigned to is the ALICE LHC Interface, or "ALICE LHC IF", a dedicated software for the control of ALICE, one of the four major experiments that are conducted along the 27 km circumference of the LHC accelerator. My virtual experience at CERN was guided by Mr. Antonio Franco and Mr. Giacinto De Cataldo that acted respectively as my coordinator and my co-supervisor for this project.

Chapter 2

ALICE LHC IF Project

ALICE LHC IF is the ALICE application of the more general LHC IF, a control software that has been mainly developed in the WinCC OA environment (see “WinCC OA” chapter) used at CERN in the controls of the LHC and of the four major experiments. In order to carry out such a distributed application, the WinCC software is used as a distributed project that interconnects many control processes running over several computers in order to provide communication channels between the different systems related to the accelerator. Data exchanged through these channels follow publication protocols, in particular DIP (“Data Interchange Protocol”) and DIM (“Distributed Information Management”) protocols, working respectively with one or multiple domain name systems (DIP is adopted by the LHC while ALICE uses DIM).

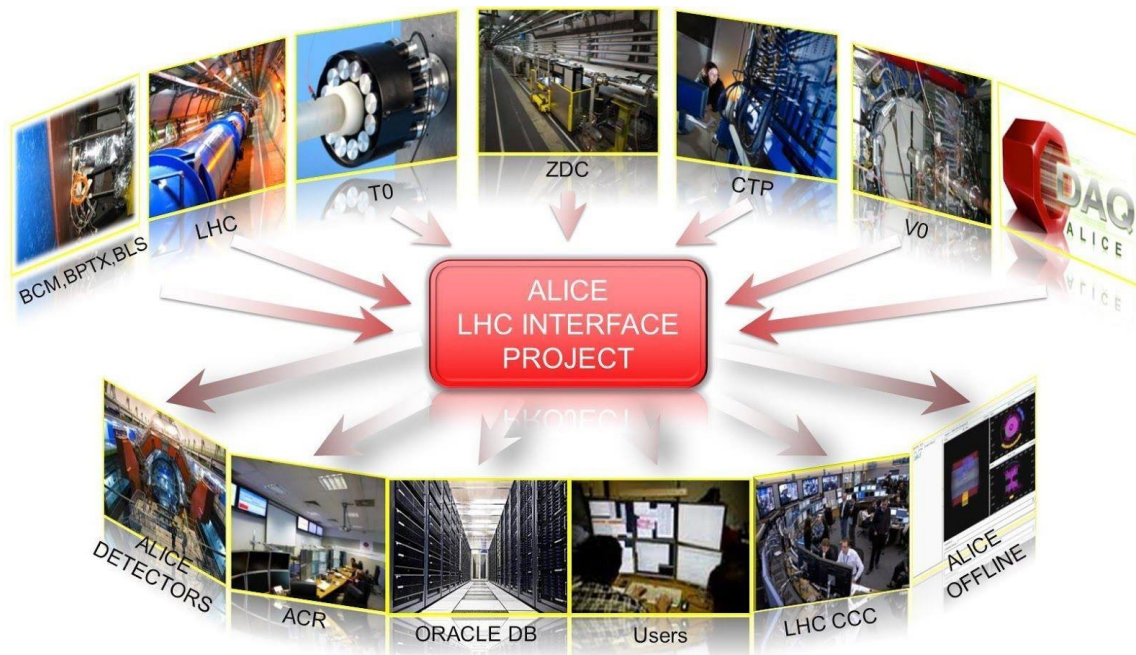


Figure 1.1: diagram of the communication channels provided by the ALICE LHC IF Project, where the displayed systems are explained in the following.

- LHC: the accelerator on which ALICE works
- BCM: an experiment that evaluates the divergence of the beam running in the LHC
- BPTX: experiment that evaluates the phase of the beam

- BLS: experiment that evaluates the beam loss
- CTP: processor that sends a trigger signal to all the electronics of ALICE when an interaction occurs
- T0, ZDC, V0: detectors that count the occurring interactions in ALICE
- DAQ: the original name for the Online system, which acquire raw data from the experiment
- ALICE Detectors: the particles detectors placed in the ALICE cavity
- ACR: Alice Control Room
- Oracle DB: the remote database of the experiment
- Users: researchers such as physicists and engineers
- LHC CCC: the control center of the accelerator
- ALICE Offline: the computing system that reconstruct the raw data acquired from the Online system

It is clear how providing a common platform for the data interchange of such distributed applications as ALICE or the entire LHC can certainly improve the control efficiency of these complex machines, making the ALICE LHC IF an essential element for the everyday activity of the experiment. The central role played by this project is also confirmed by the special functionalities and services provided, which are detailed in the following paragraphs

2.1 Functionalities

The functionalities that characterize the ALICE LHC IF Projects are reported as follows:

- **collect** parameters from the LHC, in order to acquire the status of the accelerator in real time;
- **monitor** the “Bunch By Bunch Luminosity”, meaning the number of collisions that take place each second per unit of collision area and related to each bunch of particles colliding in the ALICE cavity (Bunch by Bunch Luminosity is important to better evaluate the instantaneous Total Luminosity occurring in the experiment and to eventually detect anomalies related to specific bunches);
- **publish** ALICE information for specific clients, for example providing information to users such as physicists and scientists with relevance to a specific study;
- **produce** LHC data files that are acquired from the Online computing system and need to be passed to the Offline for reconstruction;
- **send** beams and Luminosity information to the E-Log;
- **archive** relevant data for offline Data Analysis.

2.2 Services

The services provided by the ALICE LHC IF Project are reported in the following:

- **control**, together with the ACC (“Accelerator Control Center”), the Van Deer Meer Scan Procedure and the Automatic Luminosity Levelling: the first one is a step by step scan of the beam’s cross-sectional area (on both x and y axes) that needs to be done periodically in order to acquire properties such as shape, symmetry and alignment of the beams, while the Automatic Luminosity Levelling, also called “Lumilevelling”, consists in an algorithm that ensures an efficient and fast reaching of the Luminosity target by an exponential approach; ALICE LHC IF also controls the LHC Clock Phase Shift, a clock that sends signals at a frequency of 40 MHz and synchronizes all the experiments along the LHC;
- **ensure** the experiment protection for example by putting the detectors in safety mode in case of high collision rate or by dumping the beam in case of other kinds of danger
- **maintenance** of the Control software for the Beam Instrumentation;
- **provide** the main panel that is displayed on the Big Screen in ACR (“ALICE Control Room”) and also the User Interface for the Shift Leader.

2.3 O^2 Computing System

In addition to the above mentioned special tasks already provided by the ALICE LHC IF, new important computing projects are being developed by the ALICE collaboration for the next run of the LHC, in particular the upgrade of the *O^2 Computing System*, a fusion between the Online and Offline computing systems that will ensure a partial online reconstruction and replacement of original raw data with compressed data. This innovation will allow an increased space for the online data acquisition and subsequently a higher collision rate for the experiment, which could then reach values up to 50 KHz for heavy ions. Similar outcomes are believed to be fundamental for the purposes of Run 3, which will hopefully mark a new era of important discoveries.

Chapter 3

Introduction to ALICE

My work during the online educational initiative offered this year by CERN focused on acquiring sufficient knowledge and skills to enable me to use a WinCC OA system and to program in its programming language.

As always, before I was able to practice using the software that builds the environment where ALICE LHC IF has been developed, I first needed to become familiar with some important theory concepts, in particular the reasons why this system has been selected for such an application and therefore the critical aspects that it deals with. With this in mind, my coordinator Antonio Franco began with introducing me to what ALICE is and what this experiment does, which I will endeavour to explain in detail as follows.

3.1 The experiment

ALICE is one of the four major experiments that are dislocated along the 27 km circumference of the LHC (the others are ATLAS, CMS and LHCb). Its name stands for “A Large Ion Collider Experiment” and in fact it aims to study heavy-ion physics by measuring the effects of the interaction between heavy ions (proton-ion and proton-proton interactions are also studied in this experiment) that are accelerated to a velocity close to the speed of light and that then are forced to collide in the ALICE cavity. In practical terms, bunches of heavy-ions such as lead (Pb) ions that were used for all Run 2 are accelerated by a system of accelerators that end with the LHC, in which particles circulate in two opposite beams at a velocity of more than 99,9999% the speed of light. These are then made to converge towards each other in the experiment and the products of the collision are studied. At such high energies (the interaction point reaches temperatures of almost 100,000 times the temperature of the core of the Sun), protons and neutrons melt together into their elementary constituents, quark and gluons, forming a new state of matter called Quark-Gluon Plasma (QGP) which is believed to have formed the very first Universe, about 10^{-6} s after the Big Bang (before atoms or even protons, neutrons or electrons were formed). The ALICE mission consists then in the study of this primordial soup in order to extrapolate the fundamental laws of nature, in the noble aim of understanding the origin of our universe, its present and its future. It is not so unrealistic to look at this experiment as a sort of “time machine”, but the resources and the amount of data involved for

performing such an important function is huge and that is what brings us to understanding why and how the WinCC OA System comes into play as a central element for the control of this entire project.

3.2 The problem of data management

In order to study the origin of the Universe ALICE artificially simulates a sort of mini “Big Bang” produced by the ion-collision and analyses the related effects by collecting the products of this impact with a system of particle detectors that are spread all over the experiment cavity. The amount of data produced in this operation is extremely high: there are about 3500 bunches of heavy ions (Pb has 82 protons) that impact against each other several times per second in the ALICE cavity generating a total collision energy of around 574 TeV and producing many thousands of charged particles that need to be detected. Consequently, the amount of data collected by this experiment is extraordinarily large, making ALICE the first project for event size produced compared to the other major experiments of the LHC, as shown in Fig. 3.1.

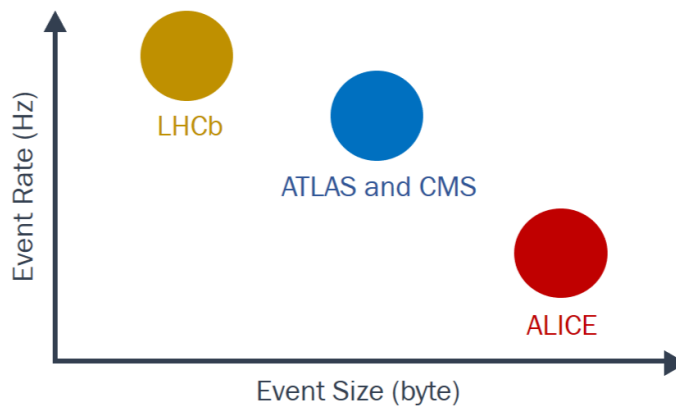


Figure 3.1: chart showing the distribution of the major LHC experiments correlated by event size produced and event rate allowed, both reported on a logarithmic scale. Due to the high amount of data recorded in ALICE, the collision frequency of this experiment must be necessarily maintained lower respect to the other ones.

It is now clear how a software that can efficiently visualize, manage and control such a large amount of data is imperatively need and the solution to this problemi s given by the WinnCC OA System, which will be explored in the following chapter.

Chapter 4

WinCC OA System

Simatic WinCC Open Architecture (WinCC OA), released by SIEMENS ETM, is a SCADA (“Supervisory Control and Data Acquisition”) software that has been adopted by CERN for the past 20 years to provide an efficient control of the distributed and complex system of the LHC, visualizing, managing and monitoring all the data coming from the instrumentation.

4.1 Main properties

The main properties that make this software such a suitable candidate for the afore-mentioned application, as well as building the environment in which the ALICE LHC IF project daily operated, are the following:

1) Open Architecture

WinCC OA allows for the integration of a wide variety of components offering finely tuned solutions from the level of automation up to operation and management level. It is also platform independent and available for Windows, Linus, iOS and Android.

2) Efficiency

The operational system of the WinCC OA software has been designed to improve the quality of the human-machine interface and to efficiently optimize the CPU. Moreover, the native 64 Bit support allows to take full advantage of high performance hardware.

3) Scalability

The architecture of WinCC OA is highly adaptable and can scale without limits to the required extensions. It provides vary from small single-site systems for machine operations up to networked redundant systems and it is clear how this special task can be a of great advantage when dealing with distributed applications such as the LHC.

4.2 Working principle

The working principle of the WinCC OA software is based on the concept of “Managers”, which are autonomous programs that communicate with each other through TCP/IP protocols in order to configure the entire SCADA system. Managers are processes with specific key functions and

therefore several types of Managers can be found in the same WinCC OA environment; the main ones are highlighted as follows.

- **Driver Manager (D):** provides access to the hardware linking processes via any number of drivers.
- **Database Manager (DB):** stores process changes in a high-speed database recording the values present “at the moment”.
- **Control Manager (CTRL):** provides a dedicated runtime environment in which programs written in Control programming language are processed.
- **User Interface Manager (UI):** takes care of the graphical display of processes states.
- **Event Manager (EV):** mediates the interaction between all the managers providing all the required communication channels.

Other Managers are also available for additional tasks, for example Remote Database Managers for the storage of process changes in a physically dislocated database (as for the Oracle Database used by the ALICE LHC IF), Archive Managers for the recording of historical data, or Distribution Managers for the management of distributed systems such as the LHC.

The communication between all these processes are unable to ensure the efficiency that distinguishes the WinCC OA software without the strong coordination exerted by the Event Manager, whose role is central and crucial in the special configuration of this system. If the structure of WinCC OA is imagined as a human organism and the different Manager as organs of this body, the Event Manager would be considered as the Heart. If we wanted to draw a diagram of this working system the Event Managers would be situated at the center and all the other managers would appear dislocated around and linked to the EV. It is thanks to this special configuration that WinCC OA can boast one of its most important characteristics, an event-oriented working principle, which makes the software a Event-Driven system, as it is explained in the following paragraph.

4.3 An Event-Driven system

WinCC OA is an Event-Driven system, generally meaning that data is processed only when a change (“event”) occurs in the system and consequently mediated and notified by the Event Manager. For example, if the User Interface Manager needs specific information from the Control

Manager it communicates this request to the Event Manager which will then report back to the UI Manager as soon as the required information is ready, therefore as soon as a value related to that information has changed (Fig. 4.1).

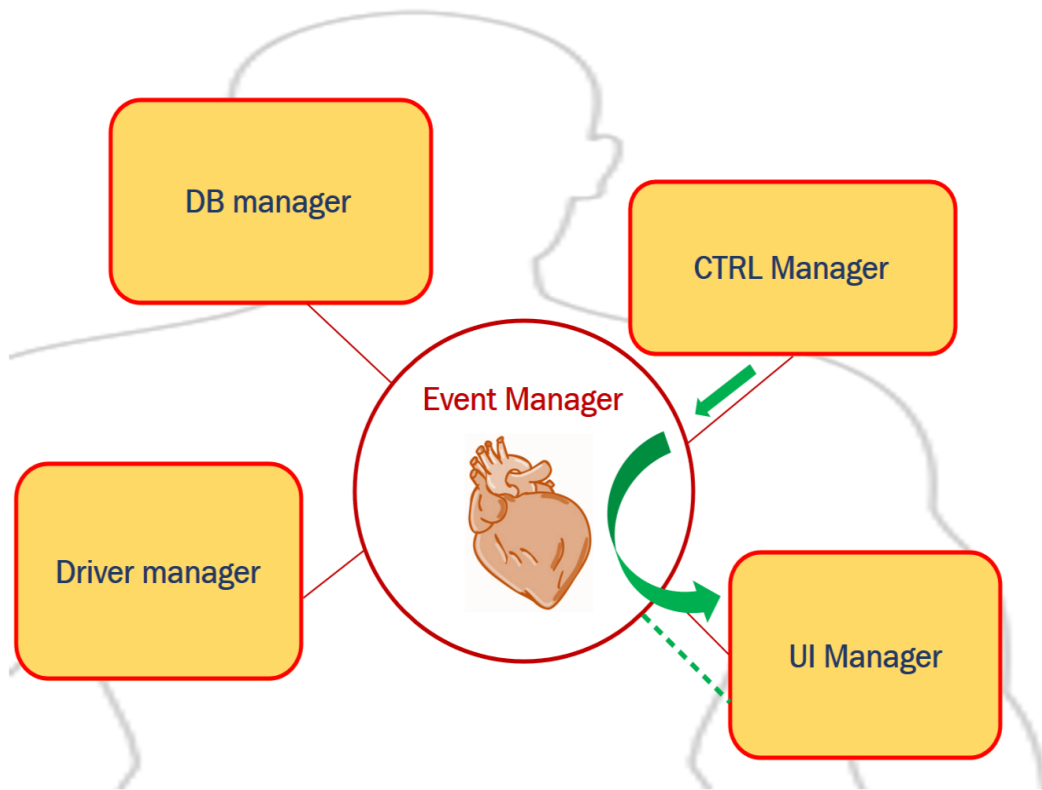


Figure 4.1: diagram that explains the basic working principle of the WinCC OA System by comparing its structure to a human organism, where managers are the organs and exchanged data is the blood.

This particular operating system oriented to the occurring events allows an optimization of the CPU usage, in fact the User Interface Manager of the previous example doesn't have to continuously interview the Event Manager to know if the required information from the Control Manager is ready, but this is immediately reported to the UI by the EV as soon as it is. This also means that the processes do not experience any delay deriving from a sampling frequency typical of a Pooling System, acquiring the events as and when they take place, which is a very important task when dealing with delicate and accurate applications such as the LHC. However, for these reasons also, the system is unable to determine if a communication channel is broken or just void of information, simply because these two situations give the same result (UI waiting for notification) and therefore auxiliary methods

are needed to do so, such as the “HeartBeat” method: following the same analogy of a human organism, the user has to understand if the body is “dead” or just “sleeping” and to achieve this goal an artificial parameter that periodically changes its value needs to be generated in order to monitor its regular notifications and subsequently check the integrity of a specific channel as a sort of heartbeat measurement. Referring to the previous example, a Heartbeat function can consist in a boolean parameter created in a Control script running in the CTRL Manager, that periodically alternates its value from ON to OFF and notifies these changes to the UI Manager. Special attention must be paid on the notification frequency which doesn’t have to interfere with the frequency of the other information, for which parameters with periodic incremental functions are preferred, but at the cost of a higher CPU usage.

HeartBeat parameters, such as all the data that reaches the UI Manager have to be efficiently visualized and managed by an operator, which is the final user of all this system and where the last but one of the most important aspects of WinCC OA comes into play: the human-machine interface, a flexible and intelligent platform processed by the UI Manager that provides a high quality interaction between software and operator.

4.4 The human-machine interface

The human-machine interface provided by WinCC OA and processed by the UI Manager is based on the concept of “panels”, which are smart windows that improve the quality of communication between software and operator thanks to an intelligent displacement of the exchanged data, ensuring also an efficient control of distributed systems such as the LHC. The enabled interaction is therefore user-friendly and allows the operator to easily visualize several parameters at the same time by optimizing the screen space. For the same reasons, changes in the system can therefore be immediately acquired and monitored by the user, which can also be helped by dedicated systems of alarm and warning (in addition to the graphical functions that can manually be created in the panel environment). Lastly, one of the most important tasks offered by the WinCC OA human-machine interface is the high flexibility of panels, which can be graphically edited by the operator who can also customize the panels’ functions to suit his personal requirements by writing his own script in appropriate programming language.

It is clear how such important tasks provided by the human-machine interface can significantly improve the operation quality of the ALICE LHC IF, facilitating the day-to-day activity of the researchers that work on the control systems of the biggest accelerator in the world.

4.5 Personal experience

My work in the 2020 online educational initiative offered this summer by CERN was channelled towards acquiring sufficient working knowledge of the WinCC OA software to enable me to create my own project for the control of a simulated complex system. Under the guidance of Mr. Antonio Franco and the co-supervision of Mr. Giacinto De Cataldo I was able to familiarize with the basic functions of WinCC OA, and gradually acquiring day after day the skills I needed to finally be qualified as a medium level user of this sophisticated software. The platform used for this training was the ALICE LHC Operation Node 1 (“alilhcon001”) terminal that I was able to access via remote desktop connection from my PC. My experience started with creating my first “project” in the WinCC OA environment (already present on the terminal) by accessing from the “WinCC OA Project Administrator” window and then making it run from the “WinCC OA Console”, which is another window where all the project managers can be visualized and controlled (the Event Manager and the Database Manager are automatically started with this operation, while the other managers can be started or stopped manually). By starting the UI Manager I could then access the environment in which panels are created and managed, the Graphic Editor window (“Gedi”), which acted as a launchpad and a testing field for all the programs subsequently wrote and that served as personal exercise to achieve the goal of acquiring familiarity with the software. The real training began generating simple “Datapoints” which are units of information written in a high-speed database and processed by the Database Manager. These units can be created, configured and monitored in the Para Module that is found on the Gedi and can then be efficiently visualized on the same interface by creating a personalized panel with the necessary functions. There are several functionalities provided by these panels and can be completely edited by acting on their scripts; this helped me to understand that knowledge of WinCC OA programming language is essential to acquire more flexibility with its use. My training then moved its focus on acquiring knowledge of the programming code, which I acknowledged is similar to C++ language and that would enable me to access many other special tasks of the system. After a couple of weeks of experience and tremendous patience on behalf of Antonio Franco, I finally mastered sufficient skills to write my own control programs of different simulated systems characterized by different types of Datapoints whose correct functioning I was able to verify by running them in the dedicated environment provided by the CTRL Manager. At this point I had acquired the basic knowledge necessary for starting my project for the creation of a control interface for a simulated complex system. At this point I had all the basics needed to start my project for the creation of a control interface for a simulated complex system. I decided to generate a virtual system of boilers that could be globally controlled on the same common platform. I initially wrote the control program for a single boiler and

tested its functioning in the dedicated runtime environment. I subsequently scaled the system to a complex of 9 boilers with 9 related control windows displayed on a new panel; the original panel scripts for the single boiler have therefore been parameterized and replicated and a new control program for the entire system was then written. Launching and testing was subsequently performed in the runtime environment. The result of this project is a virtual control interface for a complex of 9 simulated boilers (Fig. 4.2), individually linked to a specific control window provided with the following functionalities:

- displayed name of the specific boiler;
- start and stop buttons;
- indicator light for boiler status (green for ON, red for OFF);
- displayed value of current temperature (of a virtual resistance connected to the boiler);
- displayed trend of temperature over time;
- indicator light for different temperature ranges;
- dynamic displayed warning signals for different temperature conditions.

The temperature behavior of the virtual resistance connected to each of these boilers followed an incremental law considering an ambient temperature of 14 °C.

This project was not intended for practical application but served the purpose of demonstrating the acquired skills in the use of the WinCC OA System and my understanding of the capabilities that make this software the environment of the ALICE LHC Project, giving it an important role in the control of one of the biggest experiments in the world.

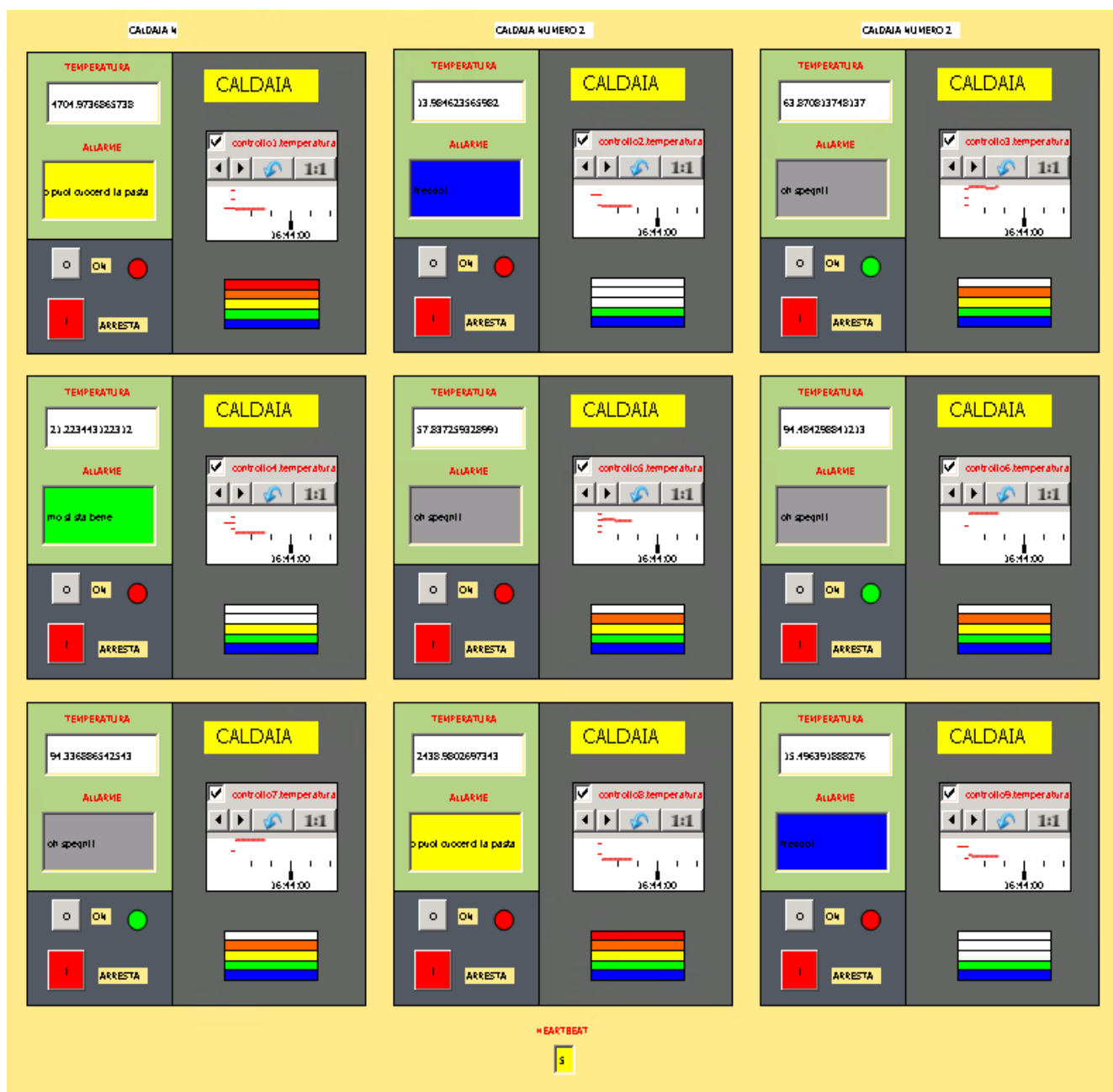


Figure 4.2: running control interface of the 9-boilers-system realized in the online educational experience

Chapter 5

Conclusion

During this 2020 online educational experience with CERN I have managed to get in contact with the leading experts in the fields of physics and engineering, acquiring important knowledge about the ALICE LHC IF Project and achieving the required abilities for the use of WinCC OA System. It was an honor for me to take part in such an interesting programme at the largest laboratory of particle physics in the world and I thank Mr. Antonio Franco, Mr. Giacinto De Cataldo and all the CERN collaboration for this amazing experience.

References

The concepts explored and explained in this Short Report are the result of the knowledge personally acquired during the CERN online educational experience offered in summer 2020, in particular from the lectures provided and from the constant teaching given by Mr. Antonio Franco.