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INTERNSHIP REPORT

START PROGRAMME 2023

Detector Control Systems in High Energy Physics Experiments

The DCS's of the BM@N Experiment at NICA and ALICE at CERN: A Comparative Study

NICA

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Summer Session 2023 (July 09 - August 19)

Dubna, 2023

Contents

Report Abstract:
This report provides an in-depth exploration of the contributions made by our efforts during the START 2023 internship period, this work includes an in-depth literature review of the existing intricacies of Detector Control Systems (DCS) deployed in high-energy physics experiments, followed by a first stage comprehensive comparative study between the DCS employed in the BM@N experiment at the NICA complex in JINR and the DCS utilized in ALICE at CERN. High-energy physics experiments necessitate meticulous control and monitoring mechanisms to ensure precise data collection and experiment integrity. The study in progress explores the hardware and software architectures, control and monitoring features, performance, and scalability of both systems.

1. Introduction

1.1 Background Information and Motivation

High-energy physics experiments, driven by the quest to unravel the fundamental mysteries of the universe, rely heavily on sophisticated technological infrastructures. Among these, the Detector Control System (DCS) plays a pivotal role in ensuring the functionality, stability, and reliability of complex experimental setups. DCS is tasked with controlling, monitoring, and safeguarding intricate detector systems, contributing to the acquisition of high-quality data critical for scientific discovery.

As high-energy physics experiments grow in scale and complexity, the development and implementation of effective DCS solutions become paramount. The accurate control of various detector parameters, real-time monitoring of experiment conditions, and swift response to anomalies are essential for maintaining experimental accuracy and reproducibility.

1.2 Research Objectives

The Research objectives adhered to during the internship period aims to:

- Conduct an extensive literature review of the existing DCS topologies, the information gathered are poised to provide valuable insights for the upcoming stages of the study.
- Carry out a comprehensive comparative analysis of the Detector Control Systems employed in two prominent high-energy physics experiments: the BM@N Experiment at the NICA complex in JINR and ALICE. By scrutinizing the design, architecture, and functionality of these DCS implementations, the research seeks to:

    1. Characterize DCS Architectures: Investigate the hardware and software components that constitute the DCS systems in both experiments, shedding light on their underlying infrastructures and interconnections.

    2. Evaluate Control and Monitoring Features: Examine the control mechanisms and real-time monitoring capabilities of the DCS in each experiment, assessing their ability to ensure the stability and safety of detectors and experimental conditions.

3. Assess Performance and Scalability: Analyze the performance metrics and scalability of the DCS systems, considering factors such as data acquisition rates, response times, and adaptability to changing experimental requirements.

4. Identify Similarities and Differences: Uncover commonalities and distinctions between the DCS implementations of ALICE at CERN and BM@N Experiment at NICA, highlighting areas of innovation and potential for cross-experiment knowledge exchange.

1.3 Scope of the Ongoing Study

The scope of the ongoing study encompasses a thorough investigation of the DCS systems deployed in the ALICE experiment at CERN and the BM@N Experiment at the NICA complex in JINR. The research will involve an in-depth analysis of relevant documentation, technical specifications, and available data pertaining to the design, architecture, and operational characteristics of the DCS systems in both experiments.

However, this study will not delve into the broader aspects of the experiments themselves, nor will it cover detailed technical aspects unrelated to the DCS systems. The primary focus remains on understanding and comparing the DCS architectures, control mechanisms, monitoring features, performance metrics, and scalability considerations of ALICE and BM@N. The insights gained from this study are anticipated to contribute to the advancement of DCS strategies in high-energy physics experiments, fostering improved experimental precision and data quality. Efforts will be made to seek publication of the findings after the completion of the study.

2. Literature Review

2.1 Detector Control System Overview

In the realm of high-energy physics experiments, where the exploration of fundamental particles and interactions is the goal, Detector Control Systems (DCS) play a pivotal role in ensuring the precision, reliability, and safety of experiments conducted at cutting-edge particle accelerators and detector arrays. DCS forms an integral part of the experimental setup, enabling scientists to capture accurate data, monitor experimental conditions, and maintain the integrity of intricate detector systems.

In the quest to understand the fundamental nature of matter and the universe, DCS systems serve as critical guardians of accuracy and reliability. They enable scientists to capture elusive particle interactions and phenomena, ensuring that the data collected is of high quality and devoid of extraneous influences. DCS systems also contribute to experiment repeatability, as they maintain consistent experimental conditions and parameters over multiple runs. DCS innovations are driven by the collaboration between physicists, engineers, and software developers, ensuring that the systems evolve to meet the challenges posed by ever more ambitious experiments. As high-energy physics experiments continue to push the boundaries of our understanding, Detector Control Systems remain indispensable tools in achieving scientific breakthroughs and expanding the frontiers of human knowledge.

Key Aspects of DCS in High Energy Physics Experiments:

1. Real-time Monitoring and Control: DCS continuously monitors the status and behavior of numerous detectors and subsystems in real time. It provides a window into the experiment's operational state, allowing for immediate response to changing conditions.

2. Data Acquisition and Management: DCS oversees the data acquisition process, orchestrating the synchronization of detectors, triggers, and data recording. It ensures that data is collected efficiently and without corruption, a critical aspect in capturing rare particle interactions.

3. Safety Measures and System Protection: DCS implements safety measures to safeguard detectors and components from potential damage. It can automatically trigger shutdowns or initiate protective actions if parameters deviate from safe ranges.

4. Experiment Integration: DCS interfaces with other experiment components, such as accelerator systems and data acquisition networks. This integration ensures seamless collaboration among various subsystems for optimal experiment performance.

5. Environmental Monitoring: DCS tracks environmental conditions, including temperature, humidity, and radiation levels, which can affect both detector performance and experimental accuracy.

6. Remote Access and Control: DCS often offers remote access capabilities, allowing researchers to monitor and adjust experiment parameters from remote locations. This is particularly beneficial for international collaborations involving multiple research institutions.

7. Adaptability and Scalability: DCS is designed to accommodate evolving experimental requirements. It can handle variations in particle flux, energy levels, and experimental conditions, ensuring flexibility and scalability.

8. Data Analysis Support: DCS systems often provide tools for preliminary data analysis and visualization. This aids researchers in quickly assessing the quality and relevance of collected data.

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2.2 DCS Constitution

The DCS is a sophisticated and multi-faceted framework that encompasses various components. The constitution of DCS in high-energy physics experiments includes hardware, software, logicware, infoware, and an organizational structure as shown in the dependency diagram below.

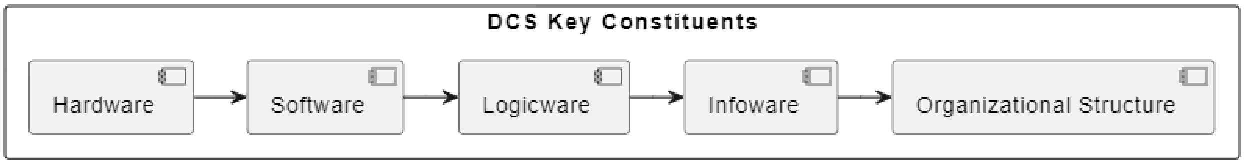

Fig.1. DCS Constitution (a dependency diagram)

1. Hardware:

The hardware component of DCS comprises physical devices and instruments necessary for the operation and monitoring of detectors and experimental systems. This includes sensors, actuators, data acquisition systems, communication interfaces, and other devices that interact with the experiment's physical components. Hardware elements collect data from detectors, trigger mechanisms, and other experiment-specific instruments, transmitting this information to the software layer for processing and analysis.

2. Software:

The software layer of DCS encompasses a range of programs, algorithms, and scripts designed to control and manage the experiment's hardware components. This includes control algorithms that regulate detector parameters, trigger conditions, and data acquisition processes. Moreover, software interfaces provide user-friendly platforms, such as Human-Machine Interfaces (HMIs), through which experiment operators and researchers interact with the DCS. The software layer enables real-time control, data visualization, and automated responses to various experimental conditions.

3. Logicware:

Logicware refers to the logical rules, scripts, and decision-making processes that govern the behavior of DCS. It involves defining conditions, thresholds, and actions that the system should take in response to specific events or measurements. Logicware ensures that the DCS reacts appropriately to anomalies, deviations, or critical events, thus maintaining the experiment's integrity and safety. For instance, logicware can dictate emergency shutdown procedures if certain conditions are met, preventing potential equipment damage.

4. Infoware:

Infoware involves managing and processing the vast amount of data generated by detectors and experiment components. It includes data processing algorithms, storage solutions, and data analysis tools. Infoware ensures that collected data is organized, archived, and made accessible for further analysis, interpretation, and collaboration among researchers. Additionally, infoware may involve data visualization tools to help researchers comprehend complex datasets.

5. Organizational Structure:

The organizational structure of DCS in high-energy physics experiments establishes roles, responsibilities, and communication channels among individuals involved in operating, maintaining, and utilizing the system. This structure encompasses researchers, engineers, operators, and other stakeholders who collaborate to ensure the efficient operation of the DCS. Clear lines of communication and well-defined responsibilities are essential to effectively manage the DCS throughout the experiment's lifecycle.

In essence, the constitution of the DCS in high-energy physics experiments is a holistic framework that synergistically combines hardware, software, logicware, infoware, and a well-structured organization. This comprehensive approach ensures that experiments are conducted with precision, reliability, and safety, allowing researchers to extract valuable insights from the intricate world of particle interactions.

2.3 Lifecycle

The life cycle of a Detector Control System (DCS) involves several key stages that ensure the successful development, implementation, and ongoing operation of the system. Here's an overview of each stage:

1. Specification:

In the specification stage, the requirements and objectives of the DCS are defined. This includes understanding the experiment's needs, the detectors involved, control and monitoring parameters, safety measures, and communication protocols. A clear and detailed specification serves as the foundation for the subsequent stages.

2. Design:

During the design phase, the architecture and components of the DCS are planned. This includes designing the hardware layout, software interfaces, user interfaces, data flow diagrams, control algorithms, and safety mechanisms. The design phase aims to ensure that the DCS will meet the specified requirements and provide effective control and monitoring.

3. Implementation:

In the implementation stage, the plans developed during the design phase are put into action. Hardware components are constructed, including sensors, actuators, and data acquisition systems. Software programs are developed to control the hardware, manage data, and provide user interfaces. Implementation involves writing code, configuring devices, and creating databases.

4. Testing:

The testing phase involves rigorous verification and validation of the DCS components. Unit tests are conducted to ensure that individual hardware and software components function as intended. Integration tests assess the interaction between different components. Functional and performance tests verify that the DCS meets the specified requirements and operates correctly.

5. Integration:

During the integration stage, the various subsystems and components of the DCS are brought together and tested as a whole. This phase ensures that all parts of the DCS work seamlessly together, communicating effectively and maintaining the required functionality. Integration may involve resolving compatibility issues and fine-tuning system interactions.

6. Maintenance:

Maintenance is an ongoing phase that occurs throughout the life cycle of the DCS. It involves routine checks, updates, and improvements to ensure the system's continued performance and adaptability. Maintenance includes addressing software bugs, hardware failures, and changes in experiment requirements. Regular monitoring and preventive measures help maintain the DCS's reliability.

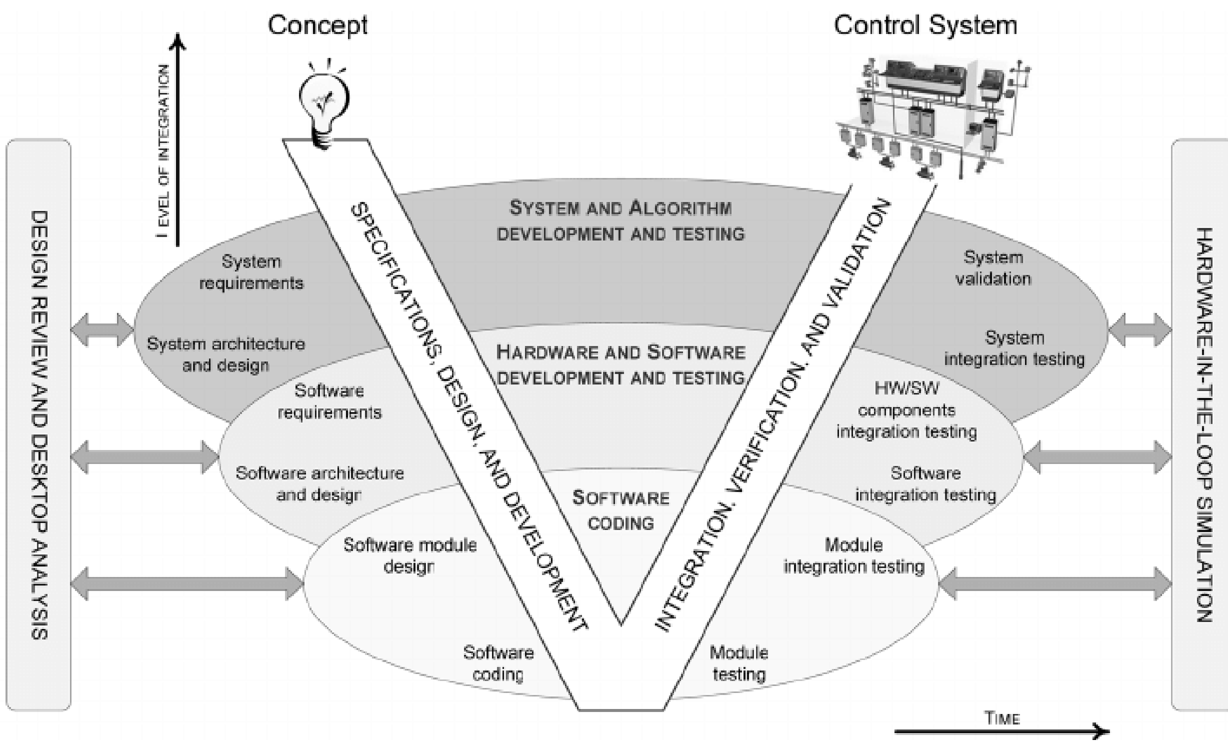

Fig.2. V-Model for control system development and initial stages of life cycle

The life cycle of a DCS is iterative and adaptable, especially in the context of high-energy physics experiments where advancements in technology and experimental demands continuously evolve. Properly managing each stage ensures that the DCS operates efficiently, provides accurate data collection and analysis, and contributes to the success of the experiment.

3. Methodology

3.1 Data Collection

3.1.1 Overview of Data Sources

The data collection process for this study was comprehensive and multifaceted, drawing from various credible sources. The sources of data included interviews with the staff of the Slow Control System department for the BM@N experiment, as well as accessing technical documents and publications for the ALICE experiment at CERN. These sources offered a well-rounded foundation for the comparative analysis of the DCS systems.

3.1.2 Data Collection Techniques

The data collection techniques employed encompassed a range of methods to ensure accuracy and depth. For the BM@N experiment, in-person visits to the experiment facilities were conducted, providing a hands-on understanding of the DCS operations. In contrast, for the ALICE experiment, data was acquired through publications and documents available on the CERN document server. Additionally, indico and wiki servers for both projects played a crucial role in gathering valuable information. This diverse approach to data collection ensured a comprehensive dataset that was credible, reliable, and well-contextualized.

3.2 Data Analysis

3.2.1 Comparative Metrics

The collected data were subjected to a comparative analysis using a set of defined metrics. The matrices used primarily include (subject to change in the later stages of the publication):

1. Architecture - Hardware and Software
2. Dataflow
3. Organization Structure and level of automation
4. Standardization

These metrics allowed for an objective evaluation of key aspects of the DCS systems in the BM@N experiment and the ALICE experiment. The application of comparative metrics facilitated a structured examination of similarities and differences between the two systems, contributing to a comprehensive understanding of their functionalities and performances.

3.2.1 Analytical Techniques

The analytical techniques employed during this study were tailored to the nature of the collected data. Notably, the data acquired for the BM@N experiment DCS was obtained through on-site interviews and visits, providing a deep insight into the operations. Conversely, the data for the ALICE experiment was sourced from published documents, with a focus on technical documentation like the Technical Design Report (TDR) and the Commissioning and Detector Readiness Report (CDR). Post-commissioning publications were also referenced to analyze the evolution of the ALICE DCS. Both projects benefitted from the availability of information on indico and wiki servers, which played a vital role in corroborating and cross-referencing data points. Rigorous fact-checking ensured the accuracy and integrity of the data, underpinning the credibility of the ensuing analysis and conclusions.

4. Data collected for the Comparative Analysis

The data collected so far for the comparative analysis is presented in this section of the report, it includes parts of the comparative metrics mentioned in Section 3.2.1 of this report like: Architecture of both H/W and S/W, Controlling and Monitoring features, GUI and Performance Scalability.

4.1 Hardware Architecture

This section will shed light on the hardware architecture of the DCS's in discussion.

4.1.1 BM@N DCS H/W Architecture

4.1.1.1 System Layout of the DCS (Decomposition Style)

The Detector Control System (DCS) of the BM@N experiment operates as an autonomous entity within the experimental setup, overseeing its specific functions without direct hierarchical oversight. Similarly, the Data Acquisition (DAQ) system and the Trigger System function as distinct and independent bodies, each managing its designated responsibilities. This decomposition style ensures that the DCS, DAQ system, and Trigger System operate cohesively while maintaining separate management structures.

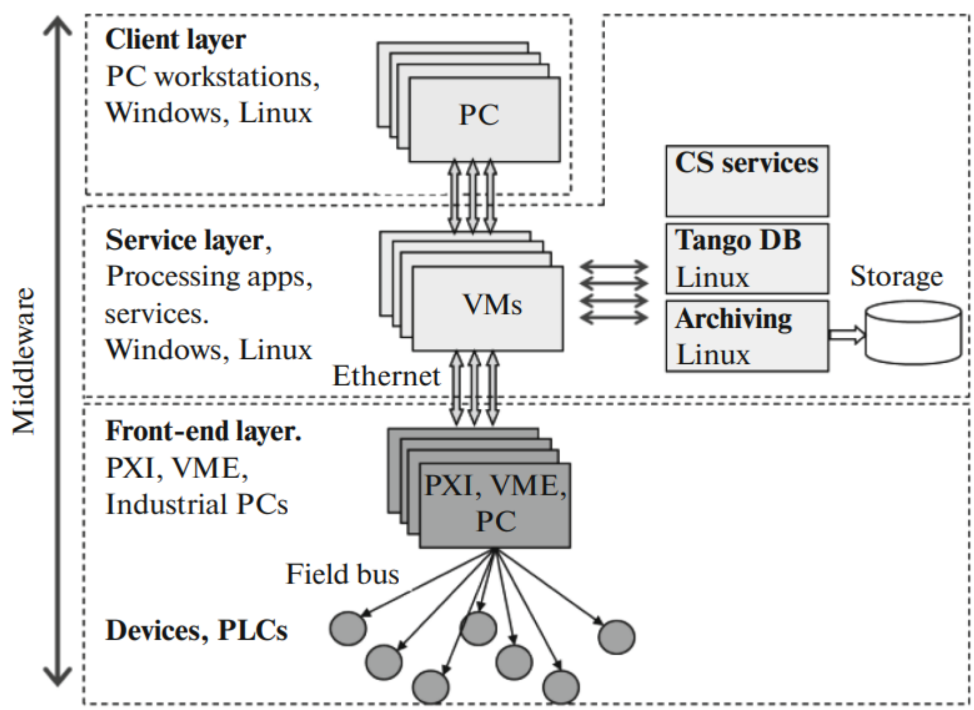

Fig.3. BM@N Control System Layout

Three layers of the BM@N control system components can be distinguished (Fig. 3):
(1) The front-end layer consists of industrial computers, intellectual controllers, and crates that directly manage equipment and gather data from sensors. The front-end computers execute low-level TANGO

programs responsible for data acquisition, equipment manipulation, and the abstraction of protocol and connection intricacies from higher-layer components.
(2) The service layer comprises high-level TANGO devices that represent complete subsystems. These devices gather data from front-end TANGO devices, process it, and implement algorithms to regulate larger subsystems. These high-level programs offer a standardized TANGO interface for whole subsystems, enabling client software to execute commands, access attributes, and perform read and write operations without necessitating knowledge of the underlying subsystem structure. Additionally, the service layer supplies a suite of services crucial for the efficient operation of the control system, encompassing administration, management of control system hardware and software, monitoring, data archiving, and development services.
(3) The client layer presents the accelerator complex state to the operator, visualizes acquired data, and empowers the operator to execute control actions. The aim is to offer a comprehensive interface enabling the operator to access the entire accelerator complex control, with the added capability to navigate to its individual components.

4.1.1.2 Hardware List

Number of Detectors Involved in the BM@N Experiment	10 (Some detectors have their own localized control systems and operate independently with minor feedback from the DCS.)
Number of Crates	8
Number of Embedded Computers or Network Devices	54
Number of Control Computers or Servers	2 (1 main server and 1 reserve server)
Number of SCADA Systems	TangoControl (sole SCADA system employed)

Table 1. Hardware list for BM@N DCS

4.1.1.3 Number of External Services Monitored by the DCS

The DCS effectively monitors several critical external services to ensure the smooth operation of the experimental environment. These services include:

- Electricity Supply
- Backup Power Systems
- Temperature Levels
- Humidity Levels
- Radiation Levels

The DCS ensures the continuous monitoring of these vital parameters, contributing to the overall safety and stability of the experiment facility.

4.1.2 ALICE DCS H/W Architecture

4.1.2.1 System Layout of the DCS (Decomposition Style)

In the CERN-style model, the Experiment Control System (ECS) supervises the Detector Control System (DCS) and acts as a logical part of the ALICE control framework. The ALICE online systems, including DCS, DAQ, TRG, and HLT, are interconnected through the ECS, forming a cohesive control layer. The ECS synchronizes and coordinates these systems, along with the LHC machine, ensuring their seamless operation. During regular operations, shift crews operate ALICE through the ECS, which also automates routine tasks and predefined sequences. This setup enhances operational efficiency and minimizes manual intervention, facilitating smooth experimentation and integration with the broader LHC facility.

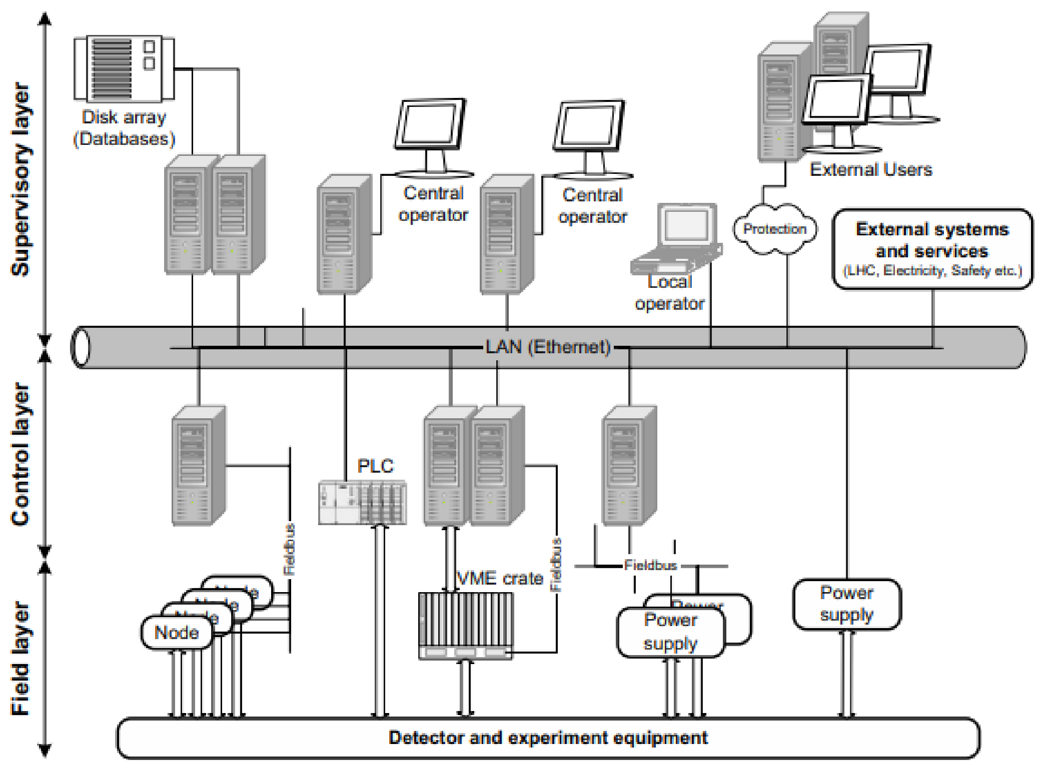

Fig.4. ALICE Control System Layout

Just like the BM@N control system, components of the ALICE DCS can also be distinguished (Fig. 4):

(1) The field layer involves devices that gather information from sub-detectors and offer services to them. ALICE is divided into multiple subsystems, each focused on specific devices like Low Voltage (LV), High Voltage (HV), Front End and Readout Electronics (FEE), etc. About 150 sub-systems, comprising around 1200 network-attached devices and 270 VME and power supply crates, are part of ALICE. Efforts have been made to standardize hardware for long-term support. The OPC protocol is the communication standard. The FEE sub-system, distinctive and specific to detectors, employs the Front End Device (FED) as a standardized access mechanism, enabling communication between FEE hardware and WINCC OA through the DIM protocol.

(2) The controls layer features computers and Programmable Logic Controllers (PLCs) that gather field layer data and send control commands. WINCC OA, a core component, is used with OPC or FED servers. WINCC OA consists of managers communicating via TCP/IP. Over 100 WINCC systems, with 1000+ managers, are deployed for ALICE. The decentralized WINCC architecture distributes processes to balance loads. It also enables the building of distributed systems for shared data and synchronized operation.

(3) The supervisory layer comprises Worker Nodes (WN) executing DCS tasks and Operator Nodes (ON) serving as dedicated servers for interactive interfaces. ONs separate interactive tasks from control functions, preventing system overload. Excessive load from user interfaces is automatically blocked, ensuring smooth operation.

4.1.2.2 Hardware List

Number of Detectors Involved in ALICE	17
Number of Crates	270
Number of Control Computers	170
Number of Embedded Computers	750
Number of Network Devices	1200
Number of Control Servers	100 (WINCC Systems)
Number of SCADA System	1 (WINCC, replacing the PVSS II system used earlier)

Table 2. Hardware list for ALICE DCS

4.1.2.3 Number of External Services Monitored by the DCS

The DCS plays a pivotal role in overseeing various essential external services to maintain seamless operation within the experimental environment. These crucial services encompass:

- Electricity
- Ventilation
- Cooling
- Magnets
- Gas
- Access Control
- Safety
- Environment
- Radiation

The DCS guarantees the ongoing monitoring of these critical parameters, thereby enhancing the experiment's overall safety and stability.

4.2 Software Architecture

This section will shed light on the software architecture of the DCS's in discussion.

4.2.1 BM@N DCS S/W Architecture

The Detector Control System (DCS) in this setup employs the Tango SCADA system for its comprehensive monitoring and control capabilities. To facilitate its implementation, specific frameworks have been utilized. The PyTango framework, designed for Python, plays a pivotal role in the development process. Additionally, PySide is harnessed to construct the graphical user interface (GUI) for the DCS, enhancing user interaction and visualization. Complementing these frameworks, the DCS integrates CAEN Crate control through gecko and custom in-house applications, adding a layer of versatility to its functionality.

The integration of the SCADA system with hardware is a meticulous process that involves connection protocols to ensure effective communication. The DCS leverages a range of protocols, including MODBUS TCP, SNMP, socket interfaces, and OPC UA, enabling seamless interactions with diverse hardware components and sub-systems. Notably, the development of Programmable Logic Controllers (PLCs) was not pursued, as the digital detector signals are directly managed by field-level electronics and subsystems, eliminating the need for intermediary PLCs.

Understanding the software structure of the DCS can be aided by referring to available documents. However, specific documents detailing this aspect were not specified. The system testing and commissioning phase is a crucial step in ensuring operational readiness. For this particular setup, rigorous system testing is performed in designated test tents, involving all detector groups, approximately 2-3 months before the initial run. Subsequent to the first run, changes were made to enhance the DCS's performance. Notably, the transition from a desktop application to a web application for monitoring and control was implemented, offering increased accessibility and flexibility. Furthermore, multiple new applications were introduced, enabling the controlled management of individual subsystems, a departure from the initial single-application approach.

The data flow architecture of the DCS, encompassing data sources and pathways, was not elaborated upon. In terms of data management, the DCS handles a substantial amount of information during each run. An estimated average of 5 million events are managed in total for the experiment, with the DAQ servers responsible for processing the experimental data portion. This comprises around 50 GB of slow control data. To accommodate this influx of data, the DCS relies on various databases. Three database servers are employed, including one dedicated to archive data and two others for reading data, such as utilizing Graphene. These servers serve not only as data repositories but also act as backups for other servers, contributing to data redundancy and system reliability.

4.2.2 ALICE DCS S/W Architecture

In pursuit of design simplification, communication standardization, and the enhancement of control capabilities, a dedicated software framework has been meticulously developed around WinCC. This framework has been crafted to provide efficient tools and guidelines, facilitating the seamless implementation of control systems for LHC detectors. Collaboratively shaped by LHC experiments and CERN EN/ICE-SCD, within the context of the Joint COntrols Project (JCOP), the framework's core stands as a testament to cooperative innovation.

Central to the framework's utility are its key tools, which encompass a Finite State Machine (FSM), alarm handling mechanisms, configuration management, archiving solutions, access control protocols, user interfaces, data exchange modalities, and robust communication capabilities. This toolkit equips developers with the resources essential for the proficient creation of control applications. For tailored applications aligned with ALICE's distinct requirements, the JCOP framework is further enriched with ALICE-specific components. These empower sub-detector experts to engineer their control applications, spanning high voltage control, front-end electronics control, and more. In a harmonious culmination, approximately 140 such applications meld into a comprehensive ALICE control system, finely tuned to orchestrate the experiment's intricate operational landscape.

The breadth of data handled by the ALICE DCS marks a paradigm shift, transcending the scope observed in prior generations of control systems. The infrastructure of the field layer demands around 1200 network-attached devices and 270 VME and power supply crates. As the curtain rises on a physics run, up to 6GB of data journey from the DCS database to the detector devices. This encompassing load incorporates WinCC recipes, encapsulating nominal device parameter values, alert thresholds, and FEE settings. Remarkably, the orchestration of ALICE for a physics run entails configuring a staggering one million parameters. This multifaceted endeavor underscores the intricate dance of technology, precision, and scale that characterizes the ALICE experiment's data handling and control prowess.

4.3 Controlling and Monitoring features

4.3.1 BM@N DCS

The Detector Control System (DCS) encompasses a range of pivotal functionalities that contribute to the seamless operation of the experiment. It provides comprehensive supervision, ensuring that all states of the experiment's subsystems are visible to shifters through a web application interface. Control mechanisms are facilitated through various graphical user applications (GUI apps), enabling shifters to efficiently manage and regulate subsystems. While no specific administrative functions or access control functionalities are mentioned, the DCS operates under different modes, with sub-detector states being localized for tailored status information. Notably, specialized automation includes the implementation of a control loop to regulate the temperature of front-end chips, which automatically cuts off low voltage if the temperature exceeds a threshold. The DCS employs a graphical representation for alarms, with different colors denoting distinct conditions. The number of alarms lies in the hundreds, spanning scenarios from hardware disconnection to voltage operations. In case of alarm-triggered emergency situations, shift leaders play a central role in providing guidance and directives for effective resolution.

4.3.2 ALICE DCS

Within the ALICE setup, the front-end electronics comprise 3276 front-end cards (FEC), each designed for specific tasks. Monitoring relies on a 12-bit SCA (Successive Approximation) ADC, encompassing various measurements. These include RTD temperature sensors, a low tolerance reference resistor for precise internal current source measurement, internal temperature sensing, shunt resistors for voltage line inputs, voltage measurements for regulators, and VTRx photocurrent measurements. Collectively, this entails 14 measurements, resulting in 12 monitoring values shared with the Detector Control System (DCS), with one value serving as a correction factor for FEC temperatures. For control purposes, each FEC's SCA manages power on/off for SAMPAs (Signal APd Readout ASICs) through GPIO signals, GBTx (Gigabit Transceiver) configuration (GBTx1 post-power-up), and potentially required GBTx tuning (GBTx0). Additionally, Common Readout Unit (CRU) monitoring through aliECS includes aspects like MPO optical power, link status, temperatures, and potential voltages. This orchestration of monitoring and control operations is facilitated with precision using protocols like ADC, GPIO, and I2C, ensuring the accuracy and efficiency of the front-end electronics within the intricate ALICE framework.

4.4 GUI and Performance Scalability

4.4.1 BM@N DCS

The User Interface (UI) of the BM@N DCS offers an organized and navigable hierarchy of panels, enabling swift access to various sub-detector systems from the main panel. This intuitive navigation enhances user interaction during operation. While there's no explicit passportization of objects or labeling (faceplates), denomination of symbols employs color coding, transitioning from green to red in case of errors, ensuring easy recognition of critical states.

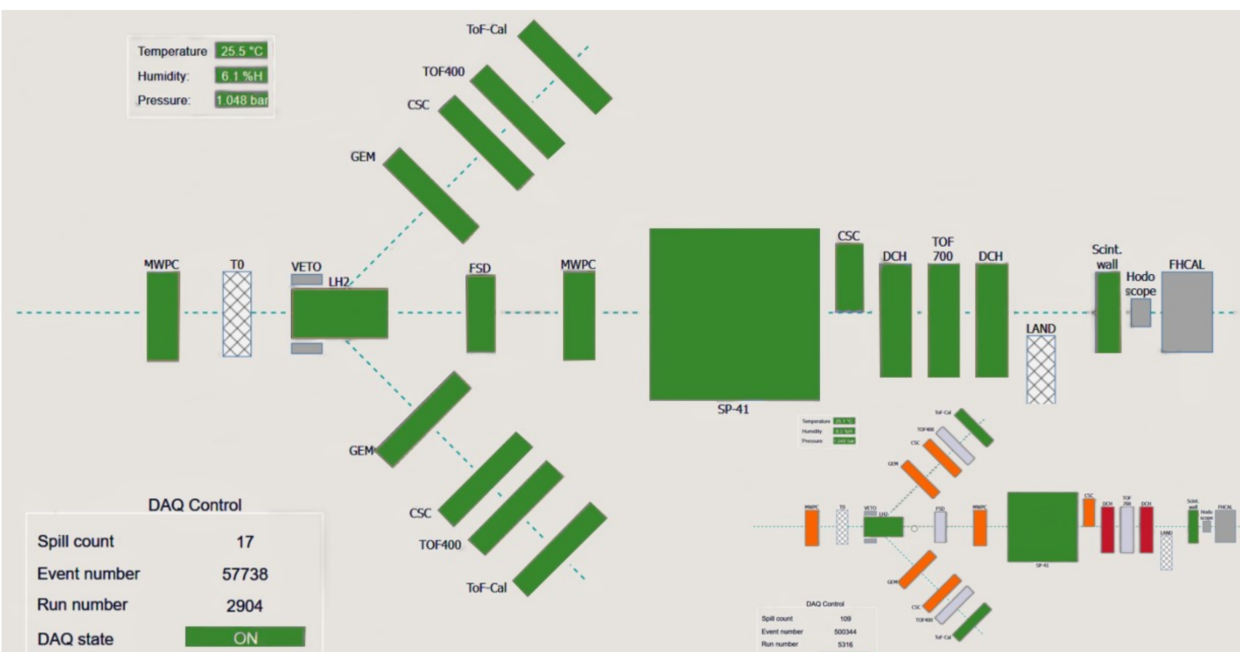

Fig.5. GUI Main Screen of BM@N DCS

The main DCS screen as shown in the above figure (Fig.5) provides a comprehensive range of information, including critical system parameters, real-time status updates, and visual representations of the experiment's components. Screenshots of the GUI during operation illustrate these data-rich displays, showcasing intricate details of the experiment's functionality and performance.

The UI configuration is structured around groups of users, optimizing efficiency by catering to specific roles rather than individual preferences. The operating software employed is Linux Debian-based, well-suited for the Tango control system. Additionally, web applications can be executed on various operating systems, ensuring flexibility and accessibility for users.

In essence, the BM@N DCS UI is designed to facilitate efficient navigation, provide vital information at a glance, and enable swift decision-making in the operation and management of the experiment's complex systems.

In terms of the performance scalability, The pre-existing Slow Control system demonstrated functionality across three successful Nuclotron runs. Archived data values from devices have been utilized for comprehensive data analysis purposes. Detector groups have effectively integrated newly developed control and monitoring applications into their operations. For the future, expansion plans involve augmenting the quantity of connected devices within the Slow Control system. Additionally, there are intentions to implement a configuration database tailored for equipment requirements. Furthermore, enhancements to the user notification system are on the horizon.

4.4.2 ALICE DCS

In the ALICE Detector Control System (DCS), a standardized Graphics User Interface (GUI) is a pivotal component employed across all detectors. Positioned as the top layer within the ALICE DCS architecture, this GUI serves as a central control hub, ensuring consistent aesthetics and functionality across all DCS components. This cohesive design is upheld through the provision of tools and guidelines, ensuring a unified "look and feel" throughout the system.

The GUI as shown in Fig.6, encompasses a variety of essential features. It includes a hierarchy browser for seamless navigation, an alert overview for quick identification of critical situations, and direct access to the Finite State Machine (FSM) and status monitoring. Commands initiated via the GUI trigger actions within different components of the system. For standard actions, the FSM mechanism is employed, while for more specialized tasks, direct interactions occur through the WINCC framework.

An integral facet of the GUI is its role-based access control mechanism, which safeguards against inadvertent errors by ensuring that only authorized individuals can execute specific actions. This mechanism bolsters the overall reliability and safety of the system. The GUI provided to operators is thoughtfully organized into distinct control and monitoring zones. This arrangement not only enhances user familiarity but also offers an intuitive overview of the entire DCS, facilitating efficient control and monitoring of the complex ALICE experiment.

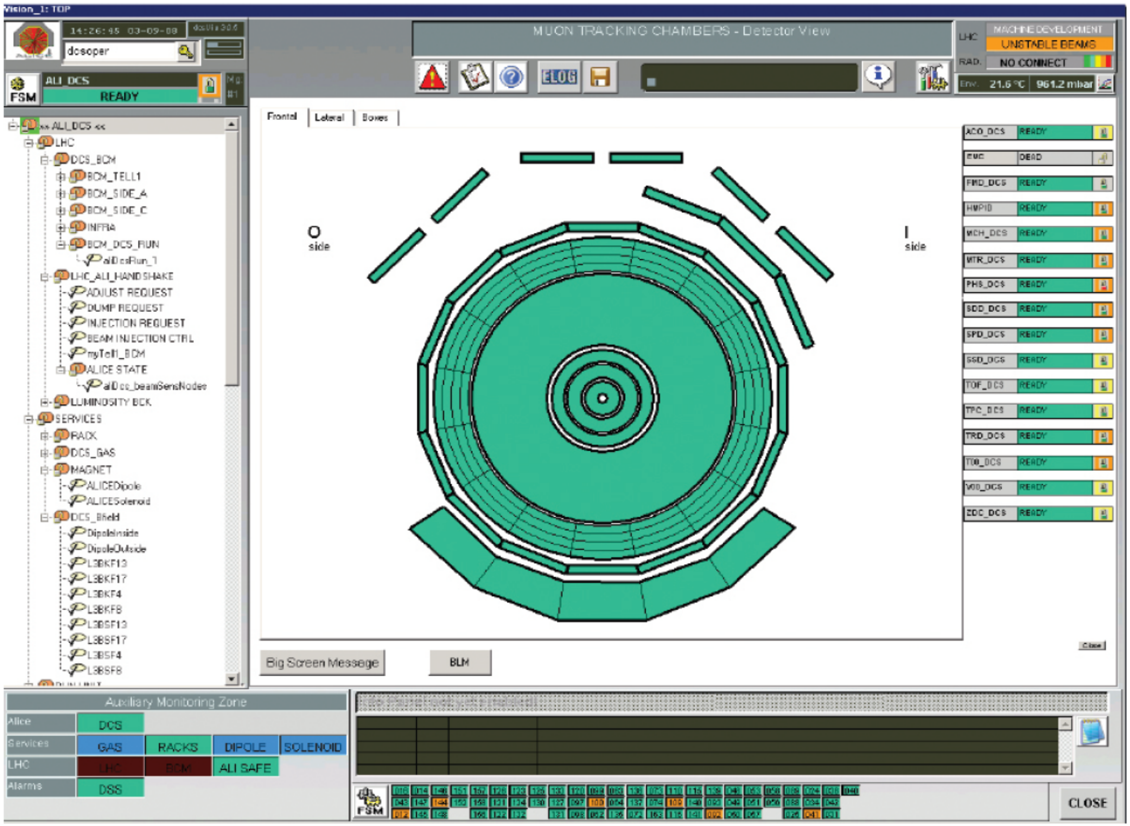

Fig.6. GUI Main Screen of BM@N DCS

By early 2007, the controls infrastructure at the experimental site was up and running, encompassing backend systems and shared services. During 2008, the integration and commissioning of the complete ALICE DCS were executed alongside the detectors, requiring around 100 integration sessions to comprehensively test all functionalities. Detector-focused sessions ensured the validation of system components' operational functionality and adherence to ALICE guidelines. Emphasis was placed on detector safety and interlock commissioning. Parallel common sessions demonstrated that ALICE DCS could be managed from a single control room post. These sessions evaluated backend infrastructure performance and system aspects like network traffic and archival rates. Controlled disturbances were introduced to identify potential anomalies, contributing to system refinements. Thanks to meticulous development, integration, and testing, ALICE DCS was fully operational ahead of the LHC startup, significantly supporting the successful operation of the ALICE experiment during its initial beam phases. The focus on performance scalability ensured the system's readiness for evolving experimental demands and changing conditions.

5. Conclusion

In conclusion, this report has presented a comprehensive overview of the Detector Control Systems (DCS) used in high-energy physics experiments, with a focus on the DCS of the ALICE experiment at CERN and the BM@N Experiment at the NICA complex in JINR. The aim of this report was to provide insights into the DCS architectures, control mechanisms, monitoring features, performance metrics, and scalability considerations of both experiments.

The data collected for this comparative analysis forms a critical foundation for the ongoing comparative study. While the detailed comparative analysis is yet to be performed, the data collected will serve as the basis for this essential evaluation. The comparative study will delve into the similarities and differences between the DCS systems of ALICE and BM@N, shedding light on the strengths and potential areas for improvement in both systems. It's important to note that this ongoing comparative study holds immense value for the field of high-energy physics experiments. As stated in the scope of study section, the aim is to publish the results of this comparative analysis as a future reference for researchers, engineers, and professionals in the field. The anticipated publication will contribute to the wider understanding of DCS strategies and their impact on experimental precision and data acquisition.

In summary, while the comparative study is currently ongoing, this report has laid the groundwork by presenting the collected data and highlighting the significance of the upcoming analysis. The future publication resulting from this study will provide a valuable resource for the scientific community, furthering advancements in DCS methodologies and enriching the overall knowledge base of high-energy physics experiments.

Acknowledgement

I would like to express my sincere gratitude to the Veksler and Baldin Laboratory of High Energy Physics at JINR for providing me with the invaluable opportunity to undertake my Summer 2023 internship. It has been an honor to be part of such a dynamic and pioneering research environment. I am deeply thankful to Mr. Nikita Baldin for his exceptional guidance, mentorship, and unwavering support throughout the duration of my internship. His insights, expertise, and dedication have enriched my learning experience and contributed significantly to my personal and professional growth. I would also like to extend my appreciation to the entire team at the laboratory for their warm welcome, willingness to share knowledge, and collaborative spirit. The exposure to cutting-edge research and the vibrant academic community have left an indelible impact on my understanding of high-energy physics.

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