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Foreword

Dear Colleagues,

SCYR is a Scientific Event focused on exchange of information among young scientists from Faculty of Electrical Engineering and Informatics at the Technical University of Košice – series of annual events that was founded in 2000. Since 2000, the conference has been hosted by FEI TUKE with rising technical level and unique multicultural atmosphere. Due to **COVID-19** lockdown, **SCYR 2020** skipped the event and was published as **Nonconference Proceedings of Young Researchers**. The primary aim, to provide a forum for dissemination of information and scientific results relating to research and development activities at the Faculty of Electrical Engineering and Informatics, has been achieved. Approx. 73 participants, mostly by doctoral categories, were active this year.

Faculty of Electrical Engineering and Informatics has a long tradition of students participating in skilled labor where they have to apply their theoretical knowledge. SCYR is opportunities for doctoral and graduating students use this event to train their scientific knowledge exchange. Nevertheless, the original goal is still to represent a forum for the exchange of information between young scientists from academic communities on topics related to their experimental and theoretical works in the very wide spread field of a wide spectrum of scientific disciplines like informatics sciences and computer networks, cybernetics and intelligent systems, electrical and electric power engineering and electronics.

Traditionally, contributions can be divided in 2 categories:

- Electrical & Electronics Engineering
- Information Technologies

with approx. 73 technical papers dealing with research results obtained mainly in university environment. The results presented in papers demonstrated that the investigations being conducted by young scientists are making a valuable contribution to the fulfillment of the tasks set for science and technology at the Faculty of Electrical Engineering and Informatics at the Technical University of Košice. Although we could not meet in person this year, we already look forward to next year's interesting scientific discussions among the junior researchers and graduate students, and the representatives of the Faculty of Electrical Engineering and Informatics. This Scientific Network usually includes various research problems and education, communication between young scientists and students, between students and professors.

We want to thank all authors for contributing to these proceedings with their high quality manuscripts. We hope this proceedings constitutes a platform for a continual dialogue among young scientists.

It is our pleasure and honor to express our gratitude to our co-organizers and to all friends, colleagues and committee members who contributed with their ideas, discussions, and sedulous hard work. We also want to thank all our reviewers.

Liberios VOKOROKOS
Dean of FEI TUKE

April 2020, Košice

Contents

Design and Implementation of Distributed Control Systems and their Selected Applications

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Abstract—**The aim of this paper is to demonstrate how the same principles of distributed system operation could be shared between the applications in different areas. For the case study we selected two examples. The first describes a control system developed by our group for the Inner Tracking System of the ALICE experiment at CERN. The second case focuses on the application of the same principles of the distributed system operation in the field of mobile robotics.**

Keywords—**Communication Interfaces, Detector Control System, Distributed Control System, Mobile Robotics**

I. INTRODUCTION

This paper deals with design and implementation of Distributed Control Systems (DiCS) in two different areas. Firstly, it describes basic concept and advantages of DiCS over Centralized Control Systems (CCS) [1]. The main focus of this paper is the overall upgrade of the ALICE experiment at CERN and brief description of newly developed hardware and software modules, including their integration within DiCS of the ALICE, that is called Detector Control System (DCS) [2]. Next it focuses on the implementation of several software modules for the DCS and their actual usage at ALICE, specifically for the Interlock system. Last but not least, the paper deals with DiCS implementation at the Center of Modern Control Techniques and Industrial Informatics (CMCT&II) at Department of Cybernetics and Artificial Intelligence (DCAI) with the focus on mobile robotics area, showing the similarity to the DCS at CERN.

II. DISTRIBUTED CONTROL SYSTEM

The DiCS is computer based control system for complex processes, where individual controllers are distributed through the system with no central supervisory control node. Unlike CCS, individual controllers are positioned closer to the controlled processes, resulting in greater reliability and lower initial costs. At the same time, superior systems have the possibility to monitor and supervise individual subsystems, thanks to which they have a comprehensive overview of the state of controlled processes. Conceptually, the DiCS can be divided into several levels of control [1]:

Level of Sensors and Actuators: (Zero Level) includes various sensors and actuators. Individual sensors and actuators can be connected to a higher level by analog, digital or frequency inputs and outputs, or by various technological interfaces. This level also includes more complex models consisting of multiple sensors and actuators.

Technological Level of Control and Regulation: (First Level) ensures the control and regulation of individual parts of the lower level while ensuring communication with the second level of DiCS. Control and regulation at this level is ensured by PLCs, technological computers and single-chip microcomputers [3].

Level of SCADA/HMI: (Second Level) includes SCADA/HMI systems for supervisory control, data acquisition and archiving. It also involves various visualizations to present production process information to the operator. Connection with lower and higher levels are provided by network interfaces mostly using TCP/IP protocol with various extensions. This level also covers simulation models implemented mostly in MATLAB/Simulink environment [4].

Information Level of Control: (Third and Fourth Level) represents the level of Manufacturing Enterprise Systems (MES) for performing production management tasks such as production and inventory control, warehouse management, or operational planning of production. These systems are based on relational databases with client web applications. It also includes the level of Enterprise Resource Planning (ERP) and Manufacturing Resource Planning (MRP) systems. This level uses the same technological resources as the third level systems and provides mainly planning of production resources and processes

Management Level of Control: (Fifth Level) is implemented on the basis of multidimensional databases using OLAP (Online Analytical Processing) technology. This level provides the resources to support strategic planning of business direction.

III. DETECTOR CONTROL SYSTEM OF ALICE EXPERIMENT

The European Organization for Nuclear Research (CERN) is the largest laboratory for basic and applied research in the field of particle physics in the world. It is located on the Swiss-French border and was founded in 1954 by the twelve founding states. The number of member states has gradually increased to 23 [5].

The CERN accelerator complex is based on several linear and circular accelerators, providing beams of particles, such as leptons (electron, positron) or hadrons (protons, atomic nuclei). The largest accelerator (the Large Hadron Collider, LHC) accelerates protons or heavy ions to ultrarelativistic energies [5]. The particle beams collide at the speed of

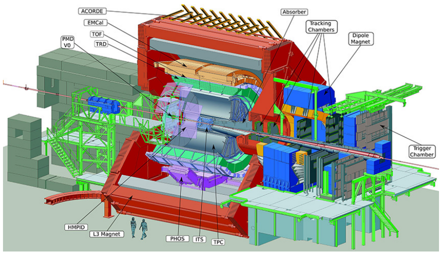


Fig. 1: The ALICE experiment and its subdetectors.

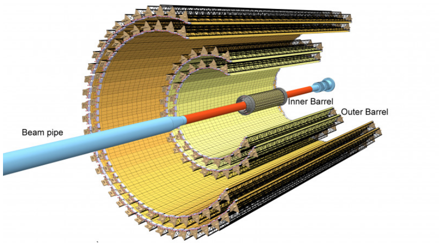


Fig. 2: Layered structure of the new ITS detector.

the light in four experimental areas, where the experiments ALICE, ATLAS, CMS and LHCb are installed. The LHC is the largest and most powerful circular accelerator in the world. It has circumference of 27 kilometers and allows the particles to accelerate to energy of 6.5 TeV with a total collision energy of 13 TeV [6].

The ALICE experiment consists of 18 detectors and is used to investigate quark-gluon plasma, which is produced by collisions of lead nuclei in LHC [6]. The properties of extremely hot plasma (200 000 times hotter than the centre of the stars) allow for a study of the processes in the early Universe, before the particles as we know them today were created. Looking into the collisions, the scientists get an deep insight into the formation of the matter and the nature of the forces that define its behavior. Main focus is on understanding of the main basic mysteries of the physics today: where does the mass come from and what is the Universe made off. The measurements suggest, that more than 70% of the Universe is made of a dark matter and dark energy that generates gravitational interactions but is not made of ordinary matter. The ALICE experiment and its subdetectors are shown in Fig. 1.

A. Upgrade of ALICE detectors for Run 3

At the end of 2018, Run 2 was finished, and thus the LHC accelerator, and all of its experiments are currently shut down for two years, with each experiment being able to upgrade their hardware and software resources [7]. After ten years of operation, the individual detectors of the ALICE experiment were removed from the underground cavern of the experiment for the purpose of maintenance and modernization.

After the upgrade, the LHC will provide by factor of 100 more collisions in ALICE compared to previous operations [8]. This will increase the data flow and ALICE will produce continuously 4TB/s of data. A new system (called O2) combines the functionality of online and offline in one place. A farm of 1600 servers equipped with GPUs will analyze the detector data as it arrives and will provide the compression based on the real time analysis of the data. This is a paradigm shift compared to the standard batch processing model, where physics data was first stored and then processed after all collisions data were collected.

To cope with these demanding requirements, the front-end electronics was completely redesigned. A common optical link (the GBT) will be used to transmit both the control and physical data. Dedicated chips (SCA, Slow Control Adapters) were deployed on the front-end cards. These allow for injection of controls data into the datastreams using dedicated bits in the data packets, hence without disturbing the physics data flow.

Our group (CMCT&II at DCAI) is directly involved in the developments of the control system for the Inner Tracking System (ITS) of the experiment. However, the developed tools became an ALICE standards and are being deployed to all upgraded ALICE subdetectors. The ITS detector is the pixel detector closest to the collision point of the beams and is used to track the trajectory of subatomic particles formed directly after collision of the beams. The original ITS detector used during Run 2 consisted of 6 layers of three different detector types - the Silicon Pixel Detector (SPD), the Silicon Drift Detector (SDD), and the Silicon Strip Detector (SSD) [9].

Unlike the original detector, the new ITS detector consist of seven layers of the Silicon Pixel Detectors, while each layer is built of the same type of sensors [10]. A schematic representation of layers of the new ITS detector can be seen in Fig. 2. The layers consist of Stave units, where each contains multiple ALPIDE chips for particle detection while providing cooling for the individual sensors. ALPIDE chips were developed by ALICE using the newest available technologies. They use a new generation of monolythic pixels, where the readout circuitry is implemented on the same chip as the pixels sensors registering the particles.

The ITS is a biggest pixel detector ever built, it could be compared to a 12 billion pixel camera with continuous readout. The new version of the detector is divided into two sections. Closer to the collision point, the Inner Barrel is made up of three layers of Half-Staves (48 in total) with 432 ALPIDE chips in total. The outer section is called Outer Barrel and consists of four layers of Staves (272 in total). A half layer of the Inner Barrel can be seen in Fig. 3.

Power supply of individual Staves is provided by PowerBoards developed by ALICE for the ITS detector. The preproduction version of the PowerBoard can be seen in Fig. 4a. One PowerBoard consists of two PowerUnits, where each PowerUnit containing 8 digital and 8 analog voltage regulators. The PowerBoard is powered by CAEN power supplies. Each PowerUnit is connected to ReadoutUnit via an I2C bus and one ReadoutUnit can handle two PowerUnits that can provide power to 8 Half-Staves or one Stave [11].

Control of the PowerBoard and the ALPIDE chips on Staves is provided by ReadoutUnit developed by ALICE for the ITS detector. ReadoutUnit is based on several FPGA chips and provides a large number of interfaces to connect detector electronics. Communication with the CRU (Common Readout

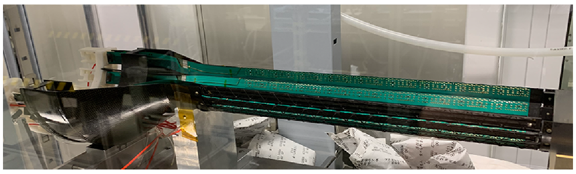
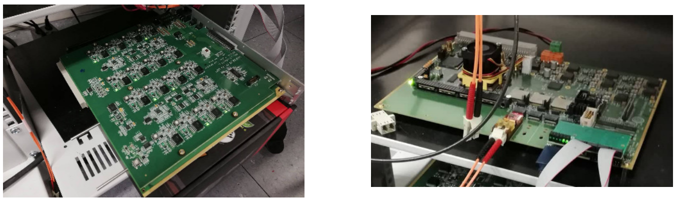


Fig. 3: Half layer of the Inner Barrel.



(a) PowerBoard (b) ReadoutUnit

Fig. 4: New electronics for the ITS detector.

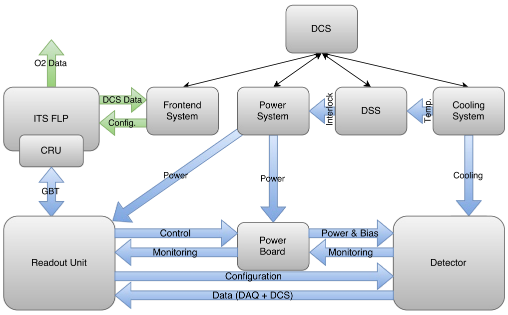


Fig. 5: New DCS system for the ITS detector.

Unit) cards is provided by two GBTx chips using the optical link [12]. The ReadoutUnit itself can be seen in Fig. 4b.

B. New structure for DCS of ALICE

The new DCS structure for the individual detectors of the ALICE experiment must ensure control of all systems critical to the operation and safety of the electronics of each detector. It must be also able to read both the DCS and the physical data that are later distributed, where the physical data are being passed to the O2 computer farms and the DCS data being sent to the higher levels of the distributed control system. The DCS must also provide continuous power supply to the individual parts of the detector as well as cooling of the electronics. In the event of critical situations such as overheating the detector parts, the DCS must be able to respond immediately and take the required action, e.g. turning off the power of corresponding part of the detector [2] .

Fig. 5 shows a schematic representation of the ITS detector crucial subsystems with their connection to the central DCS. At the highest level of control there are WinCC OA systems that ensure the archiving of received data for a offline processing and also provide the operator panels necessary for the smooth operation of the detector. Using the FSM structures, they provide an easy way to operate the detector and perform individual procedures without the need for a operator to know the physical connection of individual parts of the system. The communication between individual subsystems within the DCS is driven via the DIM network protocol [13].

FLP (First Level Processor) is a server computer that hosts multiple CRU cards. The CRU sends signals via the GBT optical link to the detector electronics and also ensures the reception and postprocess of the response. The commands sent by the CRU are used to set electronics parameters, to requests data acquisition or to upload data to the memory registers of the detector electronics. The DCS data is interleaved between the physical data within each GBT packet, whereby the FLP rips the DCS data from the stream and sends it to the front-end system. The rest of the data goes to O2 clusters for processing [14].

The most of the detectors use the SCA protocol to control their electronics, however some detectors need to communicate with the DCS system at a higher rate, so the concept of Single Word Transaction (SWT) has been introduced. The concept of SWT involves usage of whole GBT packet, not only a few bits as used with the SCA. This approach provides much higher data throughput than SCA messages. The SWT protocol is essential for the ITS detectors.

C. Implementation of the DCS

Essential part of the new DCS system is the ALFRED (ALICE Low-Level Front-End Device) architecture. The ALFRED system is independent from Readout systems and is used only by the DCS for control and monitoring of the detectors. It consists of three main modules - ALF, FRED and WinCC OA applications, while the development of the FRED module will be the main part of research activities during my PhD study.

In order to interface the CRU in a safe and efficient way, a software module ALF has been developed. The ALF is a detector independent software layer, maintained by O2, and is able to send and receive DCS data over the GBT. The communication between ALF and FRED is via DIM RPC, where FRED makes the request to ALF, and ALF publishes the response.

FRED is able to receive commands via published DIM Commands, and publish the responses from ALF via published DIM Services [15]. Commands can be complex sequences, configuration instructions, or even prompts to execute learned procedures. FRED is able to publish all response data to a supervisory control process, like the WinCC OA detector node. The FRED is able to handle multiple ALF servers in parallel and is fully customizable for detector requirements. The main idea behind the FRED is a software layer that is able to translate raw data acquired from detector electronics to real physical data and vice versa. It is also able to process error situations and determine actions that have to be done in order to recover the detector back to operational mode.

Up to now, multiple WinCC OA applications have been developed. The purpose of these detector specific nodes is to provide simple interface for human operator and execute complex tasks of detector operations in the background. One of the WinCC OA application that is currently in a commissioning phase is the Interlock system. The Interlock system takes care of safe detector operation, while monitoring connectivity and temperatures of PowerBoards and Staves of the ITS detector. It is divided into several sections monitoring individual parts of the ITS. If even one temperature sensor shows temperature out of specified limit or any ReadoutUnit stops responding, then the Interlock turns of power of all electronics in the section. The Interlock system is currently being tested by ITS experts and shows no major problems since its deployment.

IV. DiCS AT CMCT&II AT DCAI

The DiCS infrastructure at CMCT&II at DCAI can be seen in Fig. 6. Individual models of cyberphysical systems such as the Ball&Plate model, Inverted Pendulum model, Flexible Manufacturing System or individual mobile robots and robotic manipulators can be considered as Zero Level of DiCS.

On the First Level of DiCS there are PLCs and control computers of individual models, which are connected to a higher level by Ethernet or RS232 network interface. On the

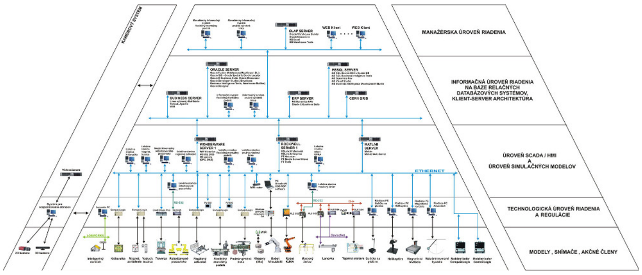


Fig. 6: Architecture of DiCS at CMCT&II at DCAI.

Second Level of DiCS are server computers with WonderWare, Rockwell and MATLAB software. Individual visualization and supervisory control is realized by local stations of models. The First and Second levels of DiCS are interconnected mostly via Ethernet interface, using communication protocols with the TCP/IP basis. In case of communication with PLC devices, the DDE or OPC protocols are used. In the application of robotic soccer, the ROS (Robot Operating System) system is used for communication between individual systems.

The Third and Fourth Levels include Oracle and MySql servers together with individual information systems implemented on ERP and Business servers. On the Fifth Level there is an OLAP server and Management Information Systems for individual models. There are also computers with client web applications for viewing the analysis. These levels are interconnected via Ethernet, using communication protocols used to access databases, such as the ODBC interface.

A. *Mobile robotics*

Development and research in area of mobile robotics is one of the focus areas of the CMCT&II [4]. The development of applications based on mobile robots within the DiCS will be also one part of the research within my PhD study. One of the mobile robotic platforms developed within CMCT&II is a robotic soccer player, which is a two-wheel differential mobile robot [1]. Although it's primary use is for robotic soccer applications, it can be used in various robotic applications when equipped with additional sensors.

The robotic soccer application also implements the concept of DiCS. It involves the three lowest levels of the DiCS architecture at CMCT&II at DCAI. A camera used for determining robots position and orientation implements the Zero Level of DiCS architecture. So do the sensors and actuators within the robot such as micromotors, encoders and additionally a gyroscope with an accelerometer.

On the First Level there are single-chip microcomputers on the robot control boards. These provide control of the movement of the robot at a lowest level, which includes controlling the speed of the robot and navigating the robot to the desired coordinates. At the same time, they provide communication with the supervisor computer via the Bluetooth interface.

The supervisor computer is located on the Second Level. It provides supervisory control of the movement of robots based on selected strategies using the ROS communication system [16]. The ROS system allows a remote control and visualization of connected robots, eventually it can be used for postprocessing and archiving of acquired data [17].

V. CONCLUSION

This paper presents an overview of Detector Control System of ALICE experiment at CERN and Distributed Control System at CMCT&II at DCAI. It shows that same principles are used in both system, what points to the versatility of Distributed Control System concept. The same principles include the multi-layer architecture of both system with usage of the similar network interfaces and protocols in both cases. Next it describes actual design and implementation of part of the DCS with emphasis on the Interlock system for ITS detector. Finally, it shows implementation of mobile robotic system into the DiCS concept.

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