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The Detector Control of the PANDA Experiment

Florian Feldbauer[a,b] **for the PANDA Collaboration**

[a] *Helmholtz-Institut Mainz, 55128 Mainz, Germany*
[b] *Johannes-Gutenberg-Universität Mainz - Institut für Kernphysik, 55128 Mainz, Germany*
E-mail: feldbaue@kph.uni-mainz.de

ABSTRACT: The PANDA experiment will be build at the antiproton storage ring HESR, a part of the new accelerator facility FAIR in Darmstadt, Germany. PANDA aims amongst others for high precision measurements in hadron spectroscopy and search for exotic matter. To guarantee the high resolution of the different components a detector control system (DCS) monitoring temperatures, humidity, pressure, and controlling chillers and power supplies is needed. The DCS of PANDA is build using the open-source software package EPICS (Experimental Physics and Industrial Control System) with a PANDA specific version of Control-System Studio.
In this document the general conecepts of the PANDA DCS will be discussed.

KEYWORDS: Hardware and accelerator control systems, Detector control systems (detector and experiment monitoring and slow-control systems, architecture, hardware, algorithms, databases).

Contents

1. The PANDA Experiment

The PANDA experiment [1] to be build at the future site FAIR (Facility for Antiproton and Ion Research) in Darmstadt, Germany, is optimized for high precision hadron physics in the charmonium mass region. The experiment utilizes an antiproton beam with high precision and high luminosity as well as a versatile detector. The produced antiprotons at FAIR are stored and cooled in the HESR (High Energy Storage Ring) with a momentum resolution of up to 10^{-5} in the momentum range between 1.5 to 15 GeV/c. The antiprotons can collide with the internal target of the PANDA experiment, providing a luminosity of up to $10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The detector consists of a target spectrometer with a solenoid magnet surrounding the interaction region and a forward spectrometer with a dipole magnet. Overall PANDA has 16 sub-detectors covering almost the complete solid angle. Precise vertex reconstruction is achieved by a vertex detector in the target spectrometer. Charged particle tracking with high resolution, precise electromagnetic calorimetry over a wide energy range as well as muon identification are provided by both spectrometers. DIRC detectors in the target spectrometer complete the particle identification system.
The experimental setup allows to address many topics in hadron physics, including the study of QCD bound states, non-perturbative QCD dynamics, hadrons in nuclear matter, hyper-nuclear physics, electromagnetic processes as well as electroweak physics. The addressed topics are discussed in detail in [1].

2. The PANDA Detector Control System

To ensure a reliable and safe operation of the experiment, the monitoring of operating parameters is mandatory. Therefore a Detector Control System (DCS) will be deployed to continuously monitor the important parameters of all sub-detectors, magnets, and the target system.
This data will be collected and provided to the shift crew while running the experiment via graphical user interfaces. The occurrence of critical values outside predefined parameter ranges needs to

create an alert or even cause an interrupt, so that measures can be taken to prevent damage to the detector. The data shall be archived in order to evaluate the detector performance over time and identify possible problems.
In addition it is foreseen to operate PANDA in different set-ups. For the hyper-nuclear physics runs e.g. the vertex detector has to be replaced [3]. Thus the PANDA DCS has to be scalable and modular. An autonomous operation of each sub-detector has to be ensured for maintenance, calibration but also for physics runs.
To fulfill these requirements the PANDA DCS is based on EPICS (Experimental Physics and Industrial Control System) [7]. EPICS provides a network based client/server model which allows to build decentralized, freely scalable control systems. The protocol used by EPICS for the network communication is called "Channel Access" (CA) and is based on UDP and TCP.

The PANDA DCS can be devided into three consecutive layers. Figure 1 shows a topological view of the control system architecture. The first layer is the "Field Layer" (FL). This layer is composed of the devices monitored and controlled by the DCS like power supplies, valves, temperature monitoring, chillers, etc.
All these devices are controlled and monitored from Input/Output controllers (IOC). These IOCs form the "Control Layer" (CL) of the PANDA DCS. In principal any device like PCs, microcontroller boards, or FPGA boards, able to manage the I/O of the corresponding sub-system can be used. The communication with the devices from the FL is realizied via a broad varity of protocols. In PANDA the CAN bus will be the main protcol but also RS485 and SNMP are used.
On the other side, the communication to other IOCs and the "Supervisory Layer" (SL) is done via gigabit ethernet. The SL is mainly found in the control room of the experiment. It covers the graphical user interfaces to the control system as well as the databases which are used for data and configuration storage.

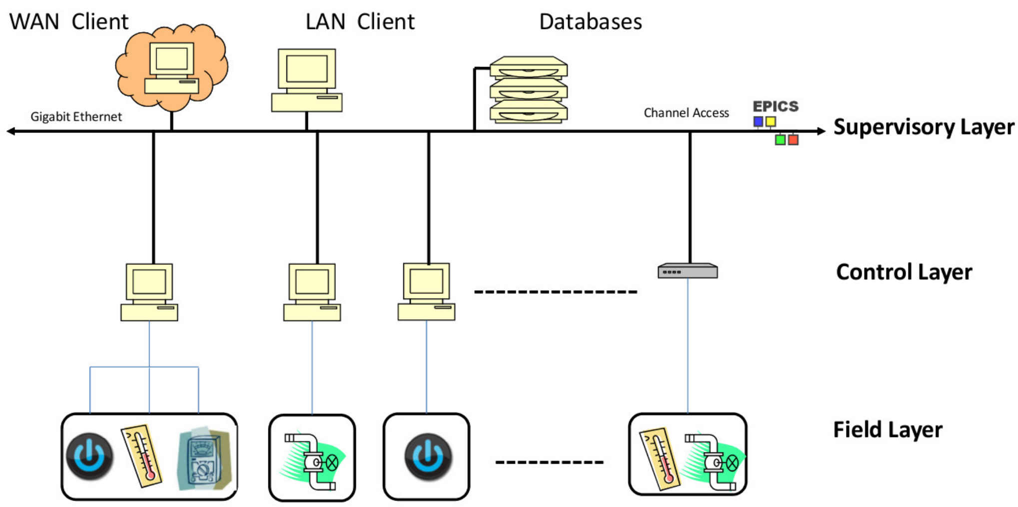

Figure 1. Topological view of the PANDA DCS.

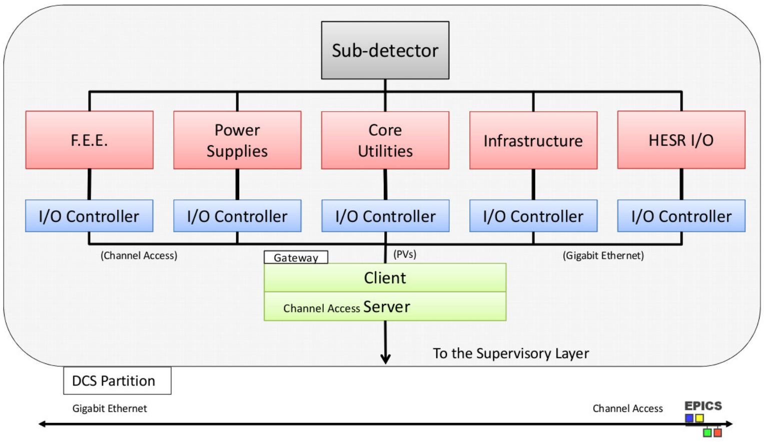

Figure 2. DCS Partition for one sub-detector. The partitions are build up of the field layer (red), control layer (blue), and the CA gateway (green).

3. DCS Partition

To achieve the modularity and autonomous operation of each sub-detector, the PANDA DCS is partitioned. For each sub-detector a local sub-network with it's own FL and CL is used capsuled from the other partitions via CA gateways (c.f. fig. 2). The number of sub-systems in the FL as well as the number of IOCs used in each partition strongly depends on the needs of the corresponding sub-detector. The structure of a DCS partition will be explained using the example of the PANDA electromagnetic calorimeter (EMC). The EMC will consist of about 16000 $PbWO_4$ scintillating crystals. Most of the crystals will be read out by two large area APDs, only the channels in the inner part of the forward endcap are read out by one vacuum photo tetrodes due to the high radiation dose to be expected in this region.
The Proto192, a prototype of the forward endcap underwent several beam tests in 2012 and 2013 [4, 5]. These tests were also used to test the prototype of the PANDA DCS under operation conditions.

3.1 Field Layer

For the signal processing FADCs and Data Concentrators are used. The DCS will be used to monitor these front-end electronic parts as well as for their configuration.
For the high voltage needed by the photodetectors, the high precision modules EHS from ISEG Spezialelektronik will be used. Power supplies from Wiener Plein & Baus Elektronik provide the low voltages for preamplifiers and ASICS.
Since the light yield of $PbWO_4$ at room temperature is rather small[1], the calorimeter will be cooled down to $-25\,^{\circ}$C. On the one hand this increases the light output by a factor of 4, on the other hand the temperature dependency is also increased to roughly 4 %/K [2]. Therefore the stability of the temperature inside the calorimeter in space and in time has to be assured. The chillers are part of the core utilities of the EMC. Additionally ultra-thin PT100 sensors are used to monitor the temperature at different positions inside this sub-detector. The PT100 are read out by the so called

[1] At room temperature the light yield of $PbWO_4$ corresponds to 0.6% of NaI

Table 1. Field Layer of the PANDA EMC.

Category	Sub-systems
F.E.E.	ADC, Data Concentrator
Power Supplies	ISEG EHS modules, Wiener PL512
Core Utilities	Chiller, light pulser, THMP, air flushing
Infrastructure	Monitoring of electronic racks and ATCA crates
HESR I/O	Beam Infos

THMP. To avoid the formation of ice inside the EMC due to moisture, compressed dried air will be flushed through the detector volume.
In addition a light pulser system will be used to monitor the transmission of the $PbWO_4$ crystals at different wavelength as well as the response of the attached photodetectors.
Temperature monitoring and cooling of the electronic racks as well as monitoring and controlling the crates holding the F.E.E. are counted amoung the infrastructure of the sub-detector's DCS partition.

The Temperature and Humidity Monitoring Board for PANDA (THMP) [5, 6] was originally developed for the PANDA EMC but is meanwhile also used by other sub-detectors.
It offers a modular read out system for temperature, humidity, pressure, and low voltages. The THMP is composed of a mainboard and piggypack boards. The mainboard holds an 14-bit, 8 channel ADC, multiplexers, filters, and a microcontroller with CAN interface. Up to eight piggyback boards can be attached to one mainboard. Currently two different versions of piggyback boards exist: One for temperature monitoring providing a constant current source with 1 mA and differential amplifiers. The THMP uses the 4-wire measurement to determine the temperature dependend resistance of the PT100. The design allows to monitor the temperature between -50 - $+50\,^{\circ}$C with a resolution of 0.02 K. The other piggyback board is used for the humidity and pressure monitoring. It only provides a $+5$ V supply voltage for the sensors. The used sensors have a voltage output linear depended on the measured value.
To each piggyback board up to eight sensors can be connected, thus one THMP can be used to read out 64 sensors. Furthermore the design of the THMP allows the user to develop additional piggyback boards for other tasks. The only condition, the piggyback board must provide a low voltage to the mainboard within the specifications of the ADC.

3.2 Control Layer

For PANDA it was decided to use IOCs running on embedded Linux devices. Currently two ARM development boards are used: The Raspberry Pi Computer [8] and the PandaBoard ES [9]. Both boards are suitable to run an EPICS IOC and provide huge flexibility communicationwise through their GPIOs.
The CLs of the individual DCS partitions are capsuled from each other through CA gateways. These gateways are not only used for capsulation but also reduce the traffic load on the network. The EPICS CA protocol uses broadcast calls to enable connections between CA client and CA server. Due to the structure used in PANDA the CA clients from the SL are not communication with every single IOC on the CL but only with the gateways for each partition.

Since the CAN bus protocol is the main communication protocol between CL and FL in PANDA the interface has to fullfil several requirements. High data throughput is needed in order to monitor all the operating parameters. The hardware has to be available now and should still be when PANDA is starting data tacking end of 2018. Reliability and an easy maintainabliliy of both, hardware and software, have to be assured and due to the compact design of PANDA the required space of the interface should be as little as possible.

To achieve all these requirements an adapter PCB for the Raspberry Pi Computer has been developed. This board uses the SJA1000 stand-alone CAN controller directly connected to the GPIOs of the ARM CPU. The kernel module for the interface is based on the open-source linux driver from Peak Systems [10]. With this interface a data throughput of about 1000 CAN frames/s at a bitrate of 125 kbit/s can be achieved[2].

4. Supervisory Layer: CS-Studio

PANDA uses an experiment specific version of Control-System-Studio (cs-studio) for the SL. On the one hand cs-studio is a collaboration between many groups, i.a. DESY, SNS, and ITER. On the other hand it is a toolkit based on Java and Eclipse RCP with a modular and pluggable infrastructure. It provides three main processes: ArchiveEngine, AlarmServer and OPI editor and runtime environment.

The ArchiveEngine uses a SQL database to store its configuration as well as write the data collected from the DCS in the same SQL database. For each monitored value individual deadbands can be configured to filter the data written to the database. This prevents the storage of noise of the channels, e.g. the noise of a high voltage channel.

The AlarmServer keeps critical operation parameters under surveillance. If a parameter's value exceeds or falls below predefined thresholds, an alarm is generated by the AlarmServer. The AlarmServer also uses SQL databases to store it's configuration and an history of occured alarms.

The last part is the editor and runtime environment for the Operators Interface (OPI). This part is used to create the user interfaces in the control room. It provides a broad quantity of widgets which can be used. It comes also with a strip chart tool which displays the data collected directly and live from the DCS as well as displaying values fetched from the archiver database.

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