Choosing between Controls and Monitoring Systems based on Programmable Logic Controllers and Programmable Automation Controllers

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Controls and monitoring systems based on Programmable Logic Controllers (PLCs) or on Programmable Automation Controllers (PACs) are used in industrial and in research applications. Jefferson Lab's Physics Division uses both types of systems. This note discusses their capabilities and recommends the control and monitoring system based on PACs for use in Jefferson Lab's Physics Division.

PLC systems were developed in 1968 to replace hardware relay control systems for the automotive manufacturing industry. Conceptually both systems are similar. For example, the ladder logic programming used in PLCs looks like wiring diagrams representing mechanical relays and connections amongst them.

A much advertised advantage of PLC systems is its capability to make "on the fly" software updates without having to reboot the system. However, this feature is rarely used in physics facilities, like Jefferson Lab, hence, does not have any value. Usually, system updates at such facilities are performed during scheduled maintenance periods.

Controls and monitoring systems based on PLCs have very limited capabilities compared to those based on PACs. Table I compares PLC and PAC hardware features.

When it comes to timing and readout rates, PLC systems run into technological roadblocks and cannot match the performance of PAC systems. For example, to investigate quenches of the solenoids and torus magnets of Jefferson Lab's Physics Division, an analog I/O rate of 10 kHz for voltage taps was mandated. The PLC systems were not able to provide this rate. To provide the 10 kHz I/O rate, PAC systems using National Instruments (NI)—a leading manufacturer of FPGA-based cRIO and PXI programmed with LabVIEW— products cRIO and PXI were implemented.

The technology research and advisory firm Automation Research Corporation (ARC) coined the acronym PAC in 2002 to distinguish PACs from PLCs.

According to ARC, PACs have five main features [1]:

1. Multi-domain functionality
2. A single, multi-discipline development platform
3. Flexible software tools that maximize process flow across machines or process units
4. An open, modular architecture
5. Compatibility with enterprise networks

PAC technology includes high-performance I/O, Field Programmable Gate Array (FPGA), and System on Chip (SoC) mixed-signal processing capabilities that PLCs do not have.

PACs have fast PC performance with high reliability, ruggedness, and flexibility. PACs can process time-critical functions at *megahertz* rates. FPGA code implemented at the hardware level excels at high-speed tasks such as custom timing, control, and signal processing for analog and digital I/O.

PAC control and monitoring systems have direct support of EPICS by the manufacturer.

In Jefferson Lab's Physics Division, PAC systems based on NI products are used for gas controls and monitoring systems, detector safety interlock systems (Silicon Vertex Tracker, Forward Tagger, and Ring Imaging Cherenkov), and for torus and solenoid magnets' DAq systems.

Like Jefferson Lab, CERN, which has been collaborating with NI since the early 1990s [2], uses PAC systems based on NI products in systems such as accelerator control and safety, machine master timing, magnet control systems, detector hardware protection systems, and detector DAq systems. Table II lists some of the CERN/LHC systems which use NI PAC systems.

To conclude, PAC controls and monitoring systems are, in terms of technological capabilities, far superior to those systems using PLCs. Additionally, PAC manufacturers support EPICS on their products.

PAC controls and monitoring systems will, in addition to providing enhanced technical capabilities, reduce overall costs—capital and operations. Capital costs are lowered by reducing software licensing outlays and the number of different types of hardware spares needed; operations costs are lowered by obviating the need to staff technical support with expertise in PLCs and with expertise in PACs. The way forward for Jefferson Lab's Physics Division is to standardize to PAC systems.

Feature	PLC	PAC
Industrially hardened hardware	x	x
Discrete control/sequential control	x	x
Process control (batch and continuous)	x	x
Integrated user-programmable FPGA/SoC in controller		x
High speed digital and analog I/O acquisition		x
Standard integration and support of EPICS by manufacturer		x
Multi-domain capabilities (one controller performs logic, process control, discrete control, motion control, monitoring, data acquisition, and data logging)		x
Distributed control functions to reduce load on central controller (examples: PID loop control, pulse generation, latching, events, and alarms on module level)		x
High density digital I/O with integral FPGA interface		x
Make control system updates without need to reboot system	x	
Integrated FPGAs available in I/O modules		x
Pre-process I/O without system controller intervention (filtering)		x
Modules can directly communicate with each other independent of controller (DMA)		x
Complex multifunction capabilities without second party hardware or software add-ons		x
Option to run on more reliable Linux systems		x
Dual FPGA and scan DAq modes available on a single controller		x
High speed, multi-axis embedded motion control		x
Permits use of open-source programming languages (C, C++, python, etc.)		x
Extensive non-proprietary communication options by manufacturer		x
Easy support for multiple vendors hardware and software		x
Integrated single development environment for all applications (discrete, analog, serial, motion FPGA, etc. Reduces programming and debug effort/time.)		x
Integrated local HMI (GUIs) interface available on controller		x

TABLE I. Comparison of PLC and PAC features.

CERN system	System type	Hardware	Comments
LHC collimator [3]	accelerator safety	PXI-FlexRio	120 PXI systems with FPGA reconfigurable I/O
LHC machine timing [4]	accelerator timing	PXI, cRIO	CERN designed cRIO module for accelerator master timing system
Kicker magnet control [5]	magnet control	cRIO	used for beam injection and extraction
LHC ground vibration monitor [6]	accelerator	cRio	three seismic stations deployed at CERN
Wall current monitoring [7]	accelerator	PXI	beam current monitoring and analysis
LHC transient recorder [8]	accelerator	cRIO	checks for AC power distribution transients
Magnet safety systems [9]	magnet safety	cRIO	systems protect LHC experimental magnets (Alice, Atlas, CMS, LHCb)
Pixel detector readout [10]	detector	PXI-FlexRio	DAq for Gas Electron Multiplier (GEM) detector
Detector safety [11]	detector	cRIO	protects detectors on NA62 spectrometer
Controls for detector positioning [12]	detector	PXI	protects detector systems if misaligned
Merlin x-ray imaging [13]	detector	PXI-FlexRio	uses Medipix3 detector chips developed at CERN

TABLE II. CERN PAC systems.

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