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PROGRESS OF THE EPICS TRANSITION AT THE ISIS ACCELERATORS

I. D. Finch*, B. R. Aljamal[1], K. R. L. Baker, R. Brodie, J. L. Fernandez-Hernando, G. Howells, M. Leputa, S. A. Medley, M. Romanovschi
STFC/RAL/ISIS, Chilton, Didcot, Oxon, United Kingdom
A. Kurup, Imperial College of Science and Technology, London, United Kingdom
[1]now at SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

Abstract

The ISIS Neutron and Muon Source accelerators have been controlled using Vsystem running on OpenVMS / Itaniums, while beamlines and instruments are controlled using EPICS. We outline the work in migrating accelerator controls to EPICS using the pvAccess protocol with a mixture of conventional EPICS IOCs and custom Python-based IOCs primarily deployed in containers on Linux servers. The challenges in maintaining operations with two control systems running in parallel are discussed, including work in migrating data archives and maintaining their continuity. Semi-automated conversion of the existing Vsystem HMIs to EPICS and the creation of new EPICS control screens required by the Target Station 1 upgrade are reported. The existing organisation of our controls network and the constraints this imposes on remote access via EPICS and the solution implemented are described. The successful deployment of an end-to-end EPICS system to control the post-upgrade Target Station 1 PLCs at ISIS is discussed as a highlight of the migration.

INTRODUCTION

The accelerators at the ISIS Neutron and Muon Source [1, 2] at Rutherford Appleton Laboratory have operated using a combination of Vsystem [3] commercial and EPICS [4] open-source control system software since Nov 2022. A full transition to EPICS is underway, but hybrid operation is expected to last several more years. (Note that ISIS Experiment Controls has already transitioned to the use of EPICS [5, 6].) During the transition, the two control systems must be run in parallel without interrupting operations. A software package called PVEcho [7, 8] has been developed to reliably bridge between the two systems.

Here we highlight the progress of the EPICS transition at the ISIS accelerators, with emphasis on lessons learned and differences with regard to the deployment at other facilities.

ARCHITECTURE OVERVIEW

EPICS controls systems may be deployed in a variety of different configurations. We have chosen to prefer the pvAccess protocol [9], prefer to run our Input/Output Controllers (IOCs) in containers [10], and use Phoebus [11] as our primary user interface.

Servers

The Vsystem control system software suite runs on a cluster of four HP Itanium servers running the OpenVMS operating system. Previously a transition to Vsystem on Linux was considered [12], but loss of expertise means that this system is now expected to be maintained as is until obsolescence.

The operational EPICS control system is deployed on a trio of Linux servers running Docker in swarm mode [13] for failover capability. Docker in swarm mode was chosen over the more complex Kubernetes (K8) [14] for orchestration of our containers as we have little need for the more advanced K8 features such as the ability to adapt to dynamic workloads. A pair of load-balancing Linux servers running haproxy [15] are deployed to manage traffic to the operational servers for further failover capability.

An additional pair of Linux servers, also running Docker in swarm mode, are used as a development and CI/CD system. Both the operational and development swarms are managed via Portainer [16]. The development system is also used for Machine Learning Operations (MLOps) [17], including training of ML models.

IOCs

All EPICS IOCs are deployed in containers running on the operational Linux servers. An unusual feature of our current deployment is that we have no conventional C/C++-based IOCs. The majority of PVs are bridged from Vsystem and are produced by PVEcho using the pvapy [18] Python library. Our first fully EPICS PVs are read from and written to ISIS Target Station 1 Omron PLCs using the CIP protocol, implemented in Python using the pvapy and CPPPO [19] libraries. For performance and maintainability reasons it is intended to migrate communications with these Omron PLCs to the MQTT protocol [20] and migrate PV management to the pvAccess for Python (p4p) [21] library.

The majority of the existing PVs managed by PVEcho are read from or written to our internally-developed CPS crates [22] via Vsystem. Prototype Python software using the p4p library has been developed to interface with the existing XML over HTTP protocol used to initialise and communicate with these crates. In the near-term the CPS-derived channels will be moved from Vsystem to EPICS, with the direction of the PVEcho bridging for these channels reversing.

The first conventional C/C++-based IOCs are being developed under contract by Mobiis [23] to interface with Omron PLCS using the FINS protocol. The code is based on an

* ivan.finch@stfc.ac.uk

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existing IOC developed by ISIS Experiment Controls and Diamond Light Source [24], with work underway to automatically convert the existing Vsystem configuration data to EPICS database definition files.

Controls Network

ISIS has an existing network controls network: a primary /22 subnet in a public IP range and two additional /22 subnets with private network addresses. Historically the controls network has been managed separately from the main ISIS network for operational and support reasons. Unlike many facilities the controls network is not isolated from the rest of the site network, though the site firewall does provide isolation from the public internet.

The configuration of the controls network means that UDP broadcast traffic is accessible across the three /22 subnets, and thus PVs are discoverable by default to all machines on the network.

PVA Gateways

PVA Gateways, a component of the p4p project, allows EPICS clients to access PVs on other networks, and also has capabilities for access control and logging.

The most important PVA Gateways in our setup are deployed on the operational servers and used to bridge between the internal Docker network and the external controls network. These PVA Gateways run outside the Docker network on bare metal; one instance for each server. This makes the PVs inside the containers available across the controls network.

Although we deploy to Docker on Linux servers, our primary development platform is Docker on Windows. Docker on Windows uses Microsoft's Windows Subsystem for Linux version 2 (WSL2), a Linux compatibility layer which itself runs in a virtual environment. The standard configuration of pvAccess uses UDP broadcast for remote PV discovery but UDP broadcast traffic is unable to cross into the WSL2 environment which is on a separate virtual network. This causes a problem when, for example, prototyping Phoebus HMIs (Human-Machine Interfaces; also called control screens) running natively on Windows but using PV(s) running within a local Docker container. Due to the UDP broadcast barrier the Phoebus HMIs running on the local machine are unable to interact with these PVs.

To overcome this we use pvAcesss in a TCP-only mode, available when connecting with known target servers, through the EPICS_PVA_NAME_SERVERS environment variable. Recent versions of Phoebus, p4p, and pvxs [25] support this directly. But in the case of older versions, pvapy, and EPICS base [26] it may be necessary to run a PVA Gateway in the Docker environment to achieve the same effect. PVs in containers remain isolated from the external network unless the EPICS_PVA_NAME_SERVERS environment variable is defined.

This approach also allows users not on our controls network remote access to PVs (depsite being unable to receive UDP broadcast traffic). We have setup read-only PVA Gateways on the load-balancer servers accessible from both our site network and via VPN. To prevent users unexpectedly entering a read-only mode the configuration of the firewalls on the load-balancers prevents access to the read-only PVA Gateways from the controls network.

USER INTERFACES

Naming Convention

At the recommendation of controls specialists from other sites, a document defining the naming convention for EPICS PVs was developed before the deployment of the first native EPICS PVs. This naming convention was developed in parallel with procurement and trial of a computerized maintenance management system (CMMS) at ISIS which uses a similar hierarchical classification of systems and sensors.

However, Vsystem channels converted to PVs by PVEcho currently retain their existing names, which do not comply with this naming convention. (There is no formal naming convention for Vsystem channels at ISIS.) Software in Python has been developed to automate the conversion of existing Vsystem channel names to naming convention conformant names. The conformant names are stored in the same CouchDB records that PVEcho uses to configure its PVs.

Once channels are renamed this will have implications for existing HMIs and archiving (to be discussed).

HMIs

Phoebus is the primary user interface for operators interacting with our EPICS control system. Two types of Phoebus HMI are used by the operators at ISIS: 1) created from scratch as part of the TS1 upgrade, 2) automatically converted from existing Vsystem control screens. The auto-converted HMIs are discussed here.

Software developed to automate the conversion of existing Vsystem control screens to EPICS HMIs was previously reported [27]. This has now been improved to allow customisation and changes to the converted screens to be preserved during subsequent runs. This means that when the PVEcho PVs bridged from Vsystem are updated to make them conformant to the EPICS naming convention the converted screens can be automatically updated to use the new PV names.

Automatically converted screens range from those that need minimal correction to those that require complete redesigns. Complete redesigns may be required because the paradigm is very different in Phoebus, e.g. Vsystem screens which use picture-in-picture setups, or because executables tied to the underlying OpenVMS operating system are part of the workflow.

In the case of less complex screen corrections we have tasked the Mobiis contractors to liaise with our main control room (MCR) operators and equipment owners to complete the modifications to auto-generated HMIs, and to perform test and validation tasks. To allow comparison of live Vsystem screens and the HMIs converted for use in Phoebus, it has been necessary to develop a Vsystem test environment.

This test environment is run in a "fat" Docker Linux container running an X-Windows environment. The change in OS requires all paths embedded in the Vsystem screens (which allow operators to navigate from one screen to another) must be rewritten from OpenVMS paths to Linux paths. We recreate the existing Vsystem databases in the test environment but without any links to external hardware. Instead the values of the database channels are streamed from the live system via MQTT. This prevents users of the test environment accidentally operating equipment during testing or validation.

OTHER CONVERSION WORK

Any control system contains a significant amount of logic which may exist outside of the IOCs or equivalent, but may still be necessary for operations. For example, processes around deployment, logging, or maintenance of the IOCs or their hardware or operating system environment. In our Vsystem deployment considerable functionality was known to reside in VMSBasic programs scheduled to run at intervals between seconds and daily. In some cases these programs had been written in the early 1990s and no documentation existed other than the source code.

We identified ~850 files (516 DCL script files, 58 C, 224 VMSBasic, and 50 Python files) requiring further analysis. The Mobiis contractors documented the purpose of these files. Many were obsolete, no longer necessary due to improved logging, or would no longer be relevant due to the migration from OpenVMS to Linux containers. A number were identified as necessary and Mobiis are working to port these to EPICS, C/C++ or Python, and Linux.

Most of this old code, though operationally important, was developed rapidly or ad hoc or simply predates widespread use of unit and integration testing. This makes testing and validation after conversion to EPICS a challenge. At this time we propose to adapt our data archiving (outlined in the next section) for the purpose. Given a set of input and output channels / PVs identified by documenting the code we can replay known operational conditions and determine whether the converted code reproduces the previously observed results.

DATA ARCHIVING

Prior to commencing the transition to EPICS, a system [28] was developed to log all changes in the state of the Vsystem control system via the MQTT protocol, ingested through Telegraf [29], to the InfluxDB time-series database [30]. Vsystem channels, including those bridged from EPICS via PVEcho, are automatically recorded in InfluxDB by this system.

The EPICS Archiver Appliance [31] has also been deployed to archive all PVs produced either natively (i.e. from the TS1 Omron PLCs) or via PVEcho. This means that InfluxDB and the EPICS Archiver Appliance track roughly equivalent sets of channels. Currently InfluxDB has approximately three years of data compared to one year for the EPICS Archive Appliance.

Users may access historic data recorded to both InfluxDB and the EPICS Archiver Appliance (through the EPICS Archiver Appliance plugin for Grafana dashboards [32]) using the Grafana web dashboard [33].

The ease of adding data recorded prior to the deployment of the tools represents an important difference between InfluxDB and EPICS Archiver Appliance. Daily control system summary data from as early as 1993 and snapshots of Vsystem data at 30 minute resolution from the early 2000s are potentially available for import. As is the data in InfluxDB recorded before the start of archiving with the EPICS Archiver Appliance. The protobuf [34] based system used by the EPICS Archiver Appliance means that it is difficult to prepend this data to existing PVs, while this is a relatively simple operation in InfluxDB.

A similar restriction in the EPICS Archiver Appliance exists with regard to changing the type of a PV. Initially PVEcho implemented Vsystem binary channels as NTScalar Boolean PVs. However, we are now in the process of switching to using NTEnums to capture the full information present in these channels. The change of type in ~4,000 PVs while retaining past data in the EPICS Archiver Appliance is a challenge. Although InfluxDB does retain the data it does so by discarding metadata about the binary values, i.e. whether 1 represents True, On, High, etc.

A key advantage of the EPICS Archiver Appliance is that it can interface directly with Phoebus, allowing users to immediately call up the history of PVs on a HMI. We have explored the possibility of adding the same feature for our InfluxDB data by mimicking the API used by Phoebus to query the EPICS Archiver Appliance [35].

DEPLOYMENT FOR TARGET STATION 1

Target Station 1 (TS1) at ISIS was upgraded [36] between Apr 2021 and Nov 2022 during a planned shutdown. This included changes to the design of the target and its cooling systems, the moderators, the reflector and all their associated services. As part of the upgrade the majority of existing OMRON [37] CJ PLCs were replaced with fewer (three) newer NJ units. The upgrade was also used as an opportunity to transition most TS1 systems to monitoring via EPICS control software.

The Common Industrial Protocol (CIP) [38] was chosen to interface with the new OMRON NJ PLCs, and Python-based software called CIP PVAserver was developed [27]. This uses the pvapy library to manage PVs. A design requirement defined that the PLCs were to control the alarm state, limits, and alarm descriptions of the PVs. To achieve this the CIP PVAserver reads the value and alarm status of the channels from the PLCs in a fast loop, and reads the complete configuration details and current alarm message in a slow loop. However, the system in operation is more complex than this simple outline. A small amount of data is

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also written to the PLCs via CIP originating from Vsystem through PVEcho.

Vsystem and EPICS also interact in an automated feedback loop. Thermocouples measure the temperature of the target and these are made available as PVs as described above. The vertical and horizontal difference in temperature between pairs of thermocouples is used to estimate the centre of the beam striking the target. These values are fed into Vsystem and a script automatically adjusts the final steering magnet in the Extract Proton Beamline to keep the beam on-target. This cross-control-system feedback is described in more detail in Baker *et al.* [8]

In order to ease the burden on operators of managing multiple systems, especially one as important to operations as the alarm system, it was decided that only one alarm monitoring tool would be used in the MCR. As most ISIS channels remain on Vsystem its Valarm tool remains in sole use, with PVEcho used to make the EPICS alarms available.

Phoebus HMIs were developed to display the data from the PLC PVs to operators in the TS1 and main control rooms. These HMIs have been developed with attention to current good practice, such as using colour only to draw attention to important information and with consideration to accessibility requirements.

The entire stack of EPICS software was successfully deployed in time for TS1 commissioning and has been in use without significant issue as TS1 has moved into scientific operations.

Operators reported that easy access to trend data through the Phoebus data browser link to the EPICS Archiver Appliance was important during TS1 commissioning for diagnosis and developing understanding of novel systems. Furthermore it was observed that operators used the automatically-converted HMIs, even if conversion had not been fully successful, in order to easily access trend data from Vsystem channels through the EPICS Archiver Appliance.

In response to this a system is being tested to allow our InfluxDB time-series data to be accessed through the Phoebus data browser interface in the same manner [35].

During commissioning it was discovered that operators urgently required off-site access to HMIs for remote diagnosis of issues. This necessitated the deployment of the read-only PVA Gateways previously discussed.

FUTURE WORK

IOCs

An interface to existing NI PXI crates which reuses our existing XML protocol has been discussed. However, some diagnostic PXI crates require the ability to set PVs on remote systems. LabView libraries exist for the EPICS Channel Access protocol but not pvAccess. The choice therefore is to implement such a library or to use another already-supported messaging protocol and establish intermediary programs. Currently we favour the latter approach.

A new White Rabbit based timing system [39], backwards compatible with and intended to replace the existing analogue timing system, has been prototyped and will be deployed in the next few years. This will be controlled by EPICS. Additionally the existing Analogue Waveform System (AWS) will be replaced by a new digital system [40], also controlled via EPICS.

Network

Controlled read and write access from outside the controls network will be required in the near-future to allow remote operation by trusted and verified operators. (This is in addition to the existing read and write access from within the controls network and read-only access from outside facilitated via PVA Gateways.) This may be achieved either through the use of an SSH Bastion to act as relay or a PVA Gateway with access controls.

Our existing controls network mixes all classes of machines including operator and developer PCs, servers, network switches, and PLCs and other hardware endpoints. There is no logical separation of functions, such as isolating TS1 to its own physical or virtual network. This may necessitate a redesign of our network architecture in order to facilitate EPICS security at the network level.

User Interfaces

A high priority is to move the display of alarms to Phoebus. As discussed, from the operators' perspective, this is the only part of the control system for TS1 which remains integrated with Vsystem (Valarm). Having tested the EPICS systems and PVEcho bridge for a year we are now confident we can move all alarms across EPICS and Vsystem to the Phoebus alarm monitoring tools [41] while guaranteeing reliability. The intention is initially to closely replicate the existing Valarm workflow to ease operator transition.

One of the features most frequently requested by machine physicists at ISIS is an ability to save states of systems and subsystems at point in time (usually recorded as ”good”) and then restore to those states at a subsequent time. This is achieved in Vsystem by saving formatted text files and then manually restoring the values. The existing Save-and-Restore functionality in Phoebus [42] has been demonstrated to the operators, but a web front-end for a Python-based system that queries values from the EPICS Archiver Appliance is being prototyped.

Our Phoebus HMI screens are centrally distributed by web-server. This means that any HMIs modified by operators or other end-users cannot be easily distributed to other end-users. A system is being put in place to manage this, either by sending modified HMIs to the controls team or by giving trusted end-users access to the git repository for HMIs. The web-server regularly pulls from this repository and makes these HMIs available.

CONCLUSION

A successful deployment into operation at ISIS of an end-to-end EPICS control system (with the exclusion of alarms) has been described. The overall architecture and implementation of this system has been discussed. This system has been in operation in parallel with our existing Vsystem control system for almost a year. The plans for future improvements have been outlined.

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