MAINTAINING A HYBRID CONTROL SYSTEM AT ISIS WITH A VSYSTEM/EPICS BRIDGE[*]

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Abstract

The migration of the controls system for the ISIS accelerator from VSystem to EPICS presents a significant challenge and risk to day-to-day operations. To minimise this impact throughout the transition, a software bridge between the two control systems has been developed that allows the phased porting of HMIs and hardware. The hybrid VSystem and EPICS system also allows the continued use of existing feedback control applications that now require interaction between both control systems, for example the halo steering operation in Target Station 1. This work describes the implementation of this bridge, referred to as PVEcho, for the mapping of VSystem channels to EPICS PVs and vice versa. The position within the wider ISIS controls software stack is outlined as well as how it utilises Python libraries for EPICS. Finally, we will discuss the software development practices applied that have allowed the bridge to run reliably for months at a time.

INTRODUCTION

VSystem is a commercial product distributed by Vista Control Systems [1] which saw first use for the accelerators at the ISIS Neutron and Muon Source [2, 3] in 1998. It is run using the OpenVMS [4] operating system on Itanium servers. Like most other control systems, components in the accelerator are distributed into different channels and databases. Metadata associated with them is summarised in database (`.adb`) files which determine the data type of the channel as well as alarm configurations, display limits and labels, among other things.

The imminent obsolescence of the Itanium servers on which VSystem is run prompted a recent evaluation of alternative control systems that could be implemented at the ISIS accelerators. The evaluation concluded that the ISIS accelerator should be migrated over to EPICS to reap the benefits of being part of a wider community of developers and users of the control system, as well as access expertise of other facilities on the Rutherford Appleton Laboratory site.

The nature of ISIS as an operational facility mandates that the transition from VSystem to EPICS needs to be done in a way that minimizes impact on user runs. It was therefore decided that a phased porting of control of hardware is the desired option for the transition [5–7]. This way, conversion of Graphical User Interfaces (GUIs), referred to as control screens at ISIS, could be decoupled from the porting of control hardware and updates to systems could progress in the background. Similarly, it would mean that new systems and services could be slowly introduced part way through the transition to allow a period of adjustment and training for machine operators [8].

In order to complete the transition in this phased manner, the current state of VSystem channels needs to be replicated within EPICS to mirror the behaviour of the machine in real-time as EPICS process variables (PVs). This work outlines the overall purpose and structure of this bridging software, as well as explaining where it sits within the larger software stack of the ISIS accelerator controls. The software is named PVEcho [9] and is divided into two halves. The first is VSystem to EPICS, referred to as V2E, which replicates channels where VSystem is still the source of truth as EPICS PVs. The second is the reverse. EPICS to VSystem (E2V) provides updates from PVs where the hardware has already been ported to EPICS to Vsystem channels which do not link to hardware but are still available for operators and software to interact with. We refer to these channels as ’soft’ channels. More detail about each of these services will be provided in the following sections.

SYSTEM OVERVIEW

The current ISIS software stack consists of a mix of what we have operating currently (the OpenVMS servers and VSystem) and what we are moving towards, as well as a variety of applications that bridge the gap between the two. Recent work has involved development of systems that allow us to interface more easily with Vsystem. These services are deployed onto a cluster of Linux servers as Docker containers in Swarm mode [10] (hereafter referred to as Docker Swarm), as can be seen in Fig. 1.

The aforementioned services include an MQTT [11] broker that allows us to stream updates to VSystem channels via topics to which clients subscribe. An application running natively in the OpenVMS server transmits messages to readback topics, as well as listening for messages published on an equivalent set topic. This allows a client to set values in VSystem from outside of the OpenVMS system.

Likewise, we host a NoSQL CouchDB database to store metadata associated with the Vsystem channels. Usually stored in the proprietary `.adb` files, a service has been built that scans the live Vsystem channels at regular intervals (approximately every 15 minutes) and updates the CouchDB database with any new contents such as modified alarm limits. This application makes the configuration of the channels available to developers via read only access to the CouchDB instance.

PVEcho leverages both of these services extensively. Both

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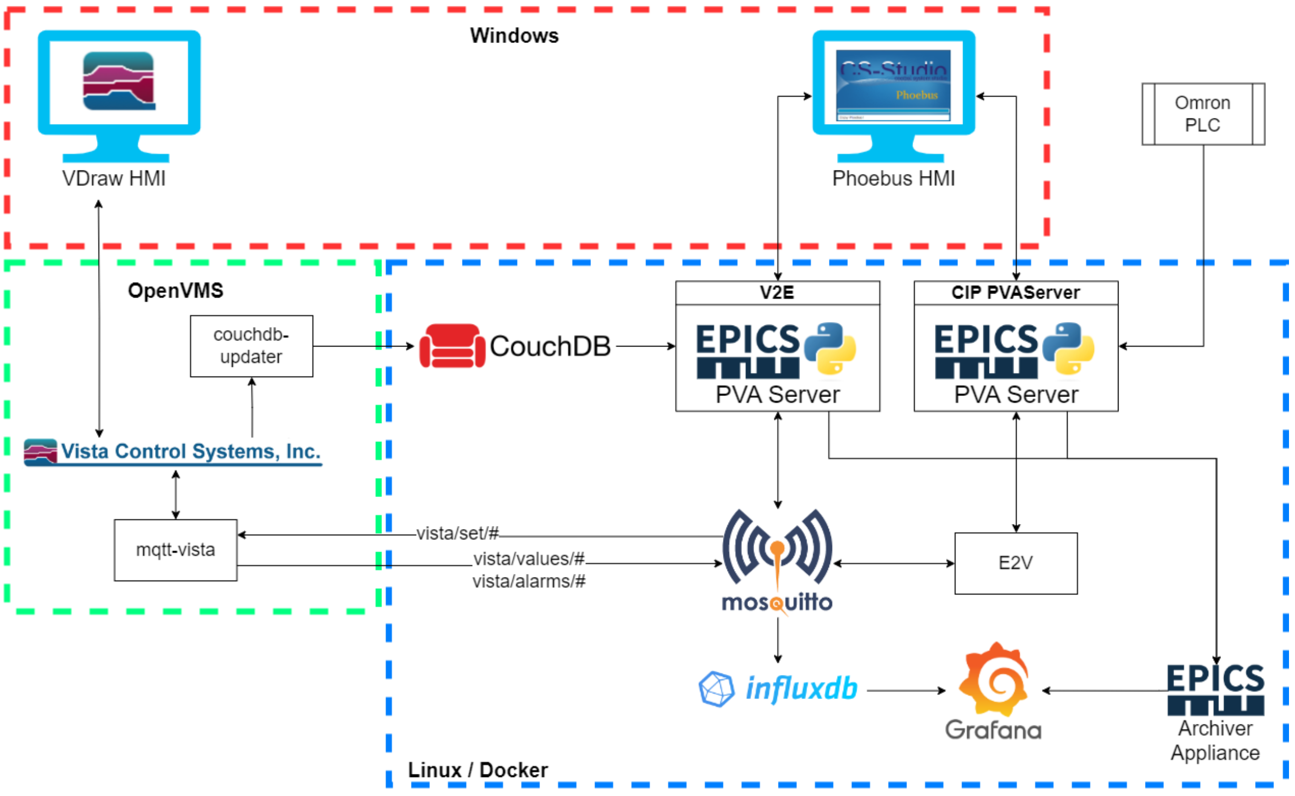


Figure 1: Illustration of where components of PVEcho sit within the larger software stack for the ISIS Accelerators and the services they interact with. Services within the red box are run on Windows machines, whereas those in the green box operate on the OpenVMS operating system. Those within the blue box are deployed as micro-services within a Docker Swarm running on Linux servers.

V2E and E2V are deployed into the same Docker Swarm, each as individual and isolated services. As a result, all PVs are contained within the Docker network, allowing access to be controlled via a PVA Gateway [8, 12].

As part of the ISIS Target Station 1 (TS1) upgrade [13], obsolete Omron PLCs were upgraded to newer models that communicate through the CIP protocol. These were integrated into EPICS using Python-based PVAServers [7, 14], which are shown in Fig. 1. Similar to PVs hosted as part of V2E, these servers are deployed into the Docker Swarm. Using E2V allows integrating these PLCs with the rest of the Vsystem control system including automated control loops and the ISIS Alarm Viewer.

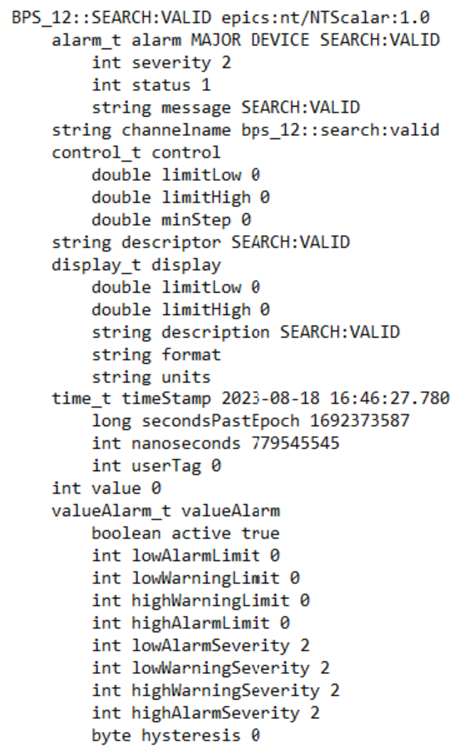
VSystem to EPICS (V2E)

As discussed, VSystem to EPICS (V2E) is the component of PVEcho that exactly replicates channels where VSystem is still the source of truth for the hardware but as EPICS PVs that utilise the pvAccess [15] (PVA) protocol. We utilise the metadata for the channels stored in CouchDB to populate the EPICS PVA structure and add the PVs to a PVAServer hosted within a Python application using pvaPy [16].

pvaPy was chosen because at the time of PVEcho's conception, it was one of the libraries that allowed dynamic addition and removal of PVs from its server without having to restart the service as would be required for a softIOC. While the ISIS accelerators are committed to preferring PVA [7, 8], it's possible that some hardware will be required to use channel access (CA) and therefore the ability of pvaPy to communicate with PVs over both protocols through its client was also a consideration when selecting the library to use. Finally, it offers flexibility over the creation of PVs that allows us to construct non-standard PV structures in a way that replicate VSystem channels more closely.

At the initiation of the project, p4p [12] was considered as the base library for PVEcho but at the time pvaPy seemed to offer a more complete set of features that suited our use case. The commitment to p4p as the primary Python library for communicating with EPICS PVs [17] had also not yet been announced but its favour over pvaPy within the community should be considered as a factor for any future significant development work on PVEcho.

Flexibility around the structure of PVs is particularly important when replicating our alarmed PVs. The majority of alarms within VSystem follow the same format as those within EPICS, where alarm limits are specified and deviation outside of the range of these limits causes an alarm to be triggered. For obvious reasons, in VSystem this type of alarm is referred to as a range alarm. However VSystem also offers two other options for alarms, referred to as match alarms and reference alarms. Match alarms are integer channels that are set to alarm on a specific value, usually representing a specific non-binary state of a system. In the current implementation of PVEcho, these alarms are configured as normal integer PVs where the application of the traditional range alarm will not apply. Using the flexibility of pvaPy we have instead constructed these PVs to adopt the same value (the value on which the PV should alarm) as all of the alarm limits within the PV's valueAlarm structure. An example of this is shown in Fig. 2. This way, a user can see from the PV structure what the alarm value is. Additional logic is implemented server side to enforce this structure whenever a PV is updated via VSystem or EPICS.



```
BPS_12::SEARCH:VALID epics:nt/NTScalar:1.0
    alarm_t alarm MAJOR DEVICE SEARCH:VALID
        int severity 2
        int status 1
        string message SEARCH:VALID
    string channelname bps_12::search:valid
    control_t control
        double limitLow 0
        double limitHigh 0
        double minStep 0
    string descriptor SEARCH:VALID
    display_t display
        double limitLow 0
        double limitHigh 0
        string description SEARCH:VALID
        string format
        string units
    time_t timeStamp 2023-08-18 16:46:27.780
        long secondsPastEpoch 1692373587
        int nanoseconds 779545545
        int userTag 0
    int value 0
    valueAlarm_t valueAlarm
        boolean active true
        int lowAlarmLimit 0
        int lowWarningLimit 0
        int highWarningLimit 0
        int highAlarmLimit 0
        int lowAlarmSeverity 2
        int lowWarningSeverity 2
        int highWarningSeverity 2
        int highAlarmSeverity 2
        byte hysteresis 0
```

Figure 2: A Vsystem 'match' alarm on an integer channel translated to an EPICS pvAccess PV.

These PVs with match alarms could be constructed as NTEnum types, making them easier to interpret. However, this requires investigation into each of the channels specific applications to decipher what the 'choices' would be, as well as gaining a better understanding of how alarms on NTEnum types are configured. This may form the basis of future work on PVEcho.

The last prominent type of alarm in VSystem is the reference alarm. These channels have their alarm limits updated according to some specified formula on changes to the other channel's value. Parameters for the formula are stored in CouchDB and therefore are implemented within the PVA server by creating a link between the PV whose value is used as a reference and that which has the alarm configured.

Once created and serving, updates to all PVs can come from one of three places. Prior to publishing the value to the PV in any of these cases, a variety of checks are run on the new state of the PV, including whether the update would place the PV into an alarm state. The parameters of the PV are updated accordingly and the new state of the PV is published.

MQTT The most common updates to the value of a PV at this stage of the transition is that VSystem will read changes to values in the hardware or operators will alter values in Human-Machine Interfaces (HMIs). Through the application running in OpenVMS, any changes to the value in VSystem will transmit an MQTT message to an MQTT topic associated with the channel containing the new value and timestamp. V2E subscribes to all the relevant topics so when a message is received, its contents are parsed into a format appropriate for EPICS and propagated through to the PVs.

Input / Output (I/O) alarms, the Vsystem equivalent of an EPICS INVALID alarm, are also transmitted as part of the mqtt-vista code. As with the value updates, V2E subscribes to the topics associated with these updates for each of the channels currently controlled by VSystem. Receipt of messages triggers an update to the alarm state of the PV based on whether the alarm has entered or left the I/O alarm state. On leaving the I/O error state, the new state of the PV is once again considered to determine whether the PV should return to a NO_ALARM, MAJOR or MINOR alarm state.

CouchDB During shutdowns and occasionally during cycle, the metadata for VSystem channels are changed, such as their alarm labels or descriptions. Through the couchdb-update service referenced in Fig. 1, these changes are broadcast as modifications to the CouchDB database. In order to apply these changes as they occur during run-time, V2E subscribes to changes to this database and re-formats the updated information as a structure that pvaPy can ingest.

EPICS As we progress with the transition, Phoebus screens that have been automatically converted from Vsystem are being adopted for use. Likewise, new high level applications are being developed to interact with EPICS rather than VSystem. Therefore, V2E needs to be able to propagate changes to the PVs created to replicate Vsystem channels back through to the hardware.

To accomplish this, a callback is assigned to the PV on creation that ingests the update to the PV and publishes an MQTT message to the topic used to set values in VSystem for that channel.

V2E has been running reliably as a service since November 2022 and has allowed us to validate the output of the auto-converted screens, as well as test other EPICS applications and services in the control room. An example of one such auto-converted screens is shown in Fig. 3 where the values in the Phoebus screen originate from hardware still connected to Vsystem.

As can be seen in Fig. 3, there are still some discrepancies between the Vsystem screens and the new EPICS ones. Some of these values represent fixed-size arrays that remove the oldest value from the beginning of the array as the most

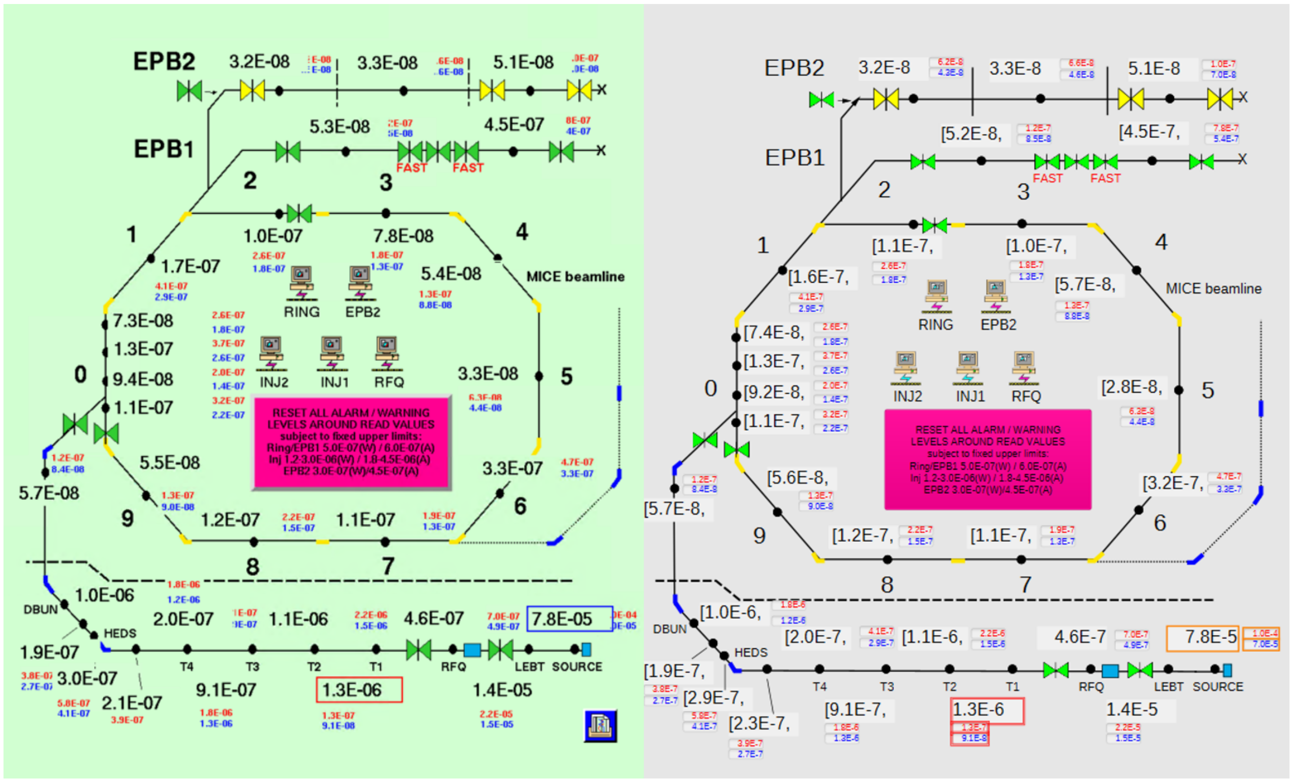

EPB2
EPB1
FAST
MICE beamline
RING
EPB2
INJ2
INJ1
RFQ
RESET ALL ALARM / WARNING LEVELS AROUND READ VALUES subject to fixed upper limits: Ring/EPB1 5.0E-07(W) / 6.0E-07(A) Inj 1.2-3.0E-06(W) / 1.8-4.5E-06(A) EPB2 3.0E-07(W)/4.5E-07(A)
DBUN
HEDS
T4
T3
T2
T1
LEBT
SOURCE

Figure 3: An example of a complicated VSystem HMI that has been auto-converted to a Phoebus Screen. Values and alarm states of the PVs are translated from Vsystem to EPICS via PVEcho's V2E component.

recent value is appended to the end, referred to as circular buffers. Vsystem screens automatically display the last value in the array whereas Phoebus displays the whole array. Comparisons like this have been one of the areas where PVEcho has been incredibly useful as it allows us to identify where the auto-conversion tool can be improved or where manual tweaks still need to be applied.

EPICS to VSystem (E2V)

As discussed earlier, although the transition to EPICS for the ISIS accelerators is underway, many applications used within the control room still rely on VSystem. Most importantly, operators still use the native VAlarm to monitor alarms in the system.

As part of the Target Station 1 upgrade that took place from June '22 to November '23, some of the PLCs for the target controls were interfaced to EPICS [7, 14]. However, legacy applications are still required to utilise their values to control equipment, as is the case for TS1 halo steering.

In this control loop, thermocouples measure the temperature at specific locations around the target. The temperature values broadcast from the Omron PLCs are made available as PVs as described in [7]. Shown in Fig. 4, the difference in temperature between horizontal and vertical pairs of thermocouples is used to estimate where the centre of the beam is striking the target. Deviation from the centre can be corrected for by changing the currents of steering magnets in the Extract Proton Beamline.

The values required for this control loop are now split across two control systems, the temperatures originating from EPICS and the magnet current settings from Vsystem. As the logic behind the control remains within VSystem, the temperature values, as well as the alarm states of the ported PVs, need to be propagated back. This is the role of the EPICS to VSystem service.

In E2V, monitor functions are defined and assigned to the PVs that propagate value changes in PVs back down the chain, where changes are affected in Vsystem via MQTT set messages. These VSystem channels need to be created manually within VSystem but can be configured to use default values, which are then populated on initialisation of the connection with the PV at start-up of the E2V service.

As part of the transition to EPICS it was decided to conform more closely with good alarm management practices [18, 19], particularly regarding the definition of what should be considered a MAJOR or MINOR alarm. However, these definitions do not conform with the internal logic implemented within the VSystem back-end. Therefore, it was not possible to rely on the channel definition within VSystem to determine the alarm state as it would cause discrepancies between the alarm state in EPICS and VSystem, ultimately confusing the operators.

Therefore, in order to exactly replicate the true alarms as they are in EPICS, equivalent binary channels for each of the PVs are also created that are activated and alarm when the PV goes into a specific alarm state. Figure 5 highlights

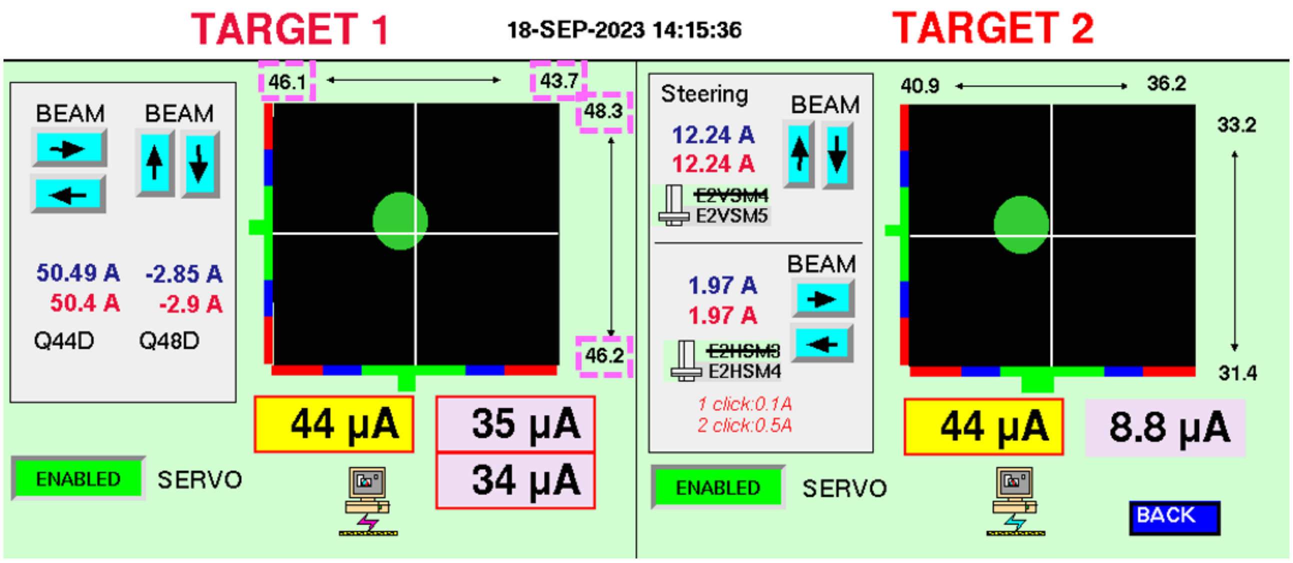
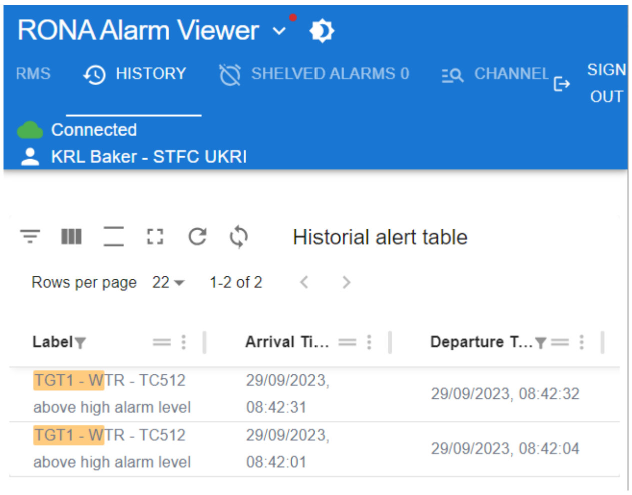


Figure 4: VSystem GUI for the ISIS Target Station 1 Halo Steering. Green circles indicate where the centre of the beam is hitting the target, calculated using temperature differences between thermocouples located on opposite sides of the target. Magnet strengths in the Extract Proton Beamline are changed to re-centre the beam. In the case of TS1 on the left of the screen, the temperature values highlighted by pink boxes, originate from PLCs that interface with EPICS rather than VSystem, where the logic for the control algorithm still remains.



Label	Arrival Ti...	Departure T...
TGT1 - WTR - TC512 above high alarm level	29/09/2023, 08:42:31	29/09/2023, 08:42:32
TGT1 - WTR - TC512 above high alarm level	29/09/2023, 08:42:01	29/09/2023, 08:42:04

Figure 5: RONA, ISIS's web based alarm viewer developed as a more accessible alternative to the Valarm component of Vsystem, displaying historical Target Station 1 alarms. The alarm states have been propagated from the PLCs via the PVAServers and PVEcho's E2V component.

the integration of these alarms into RONA, a web-based Alarm viewer developed in-house as an more feature-rich alternative to the Vsystem Alarm Viewer.

The E2V system has been operational since Target Station 1 commissioning in November 2022. It is expected that as more systems are interfaced to EPICS as the transition progresses, the PVEcho service taking the greater degree of responsibility will shift from V2E to E2V.

SOFTWARE DEVELOPMENT PRACTICES

Reliability in the hybrid system is integral, especially if it is to be used to support development of applications and control of other hardware. As we already have strict expectations for how VSystem should behave in specific cases, we were able to write a comprehensive suite of unit and integration tests to validate the behavior of the PVs for each of these cases.

Development of PVEcho in Python permitted us to use libraries that would automate the running of these tests and include them in a continuous integration and deployment (CI/CD) pipeline.

Any changes that are pushed to the codebase will execute the test suite and if merging into production, the build and deployment stages are only triggered on their successful completion. This prevents any breaking changes from being deployed into production which could cause downtime of the service. If the test suite runs successfully and meets all requirements, once the new image is built, the service is automatically restarted using the new image.

Deployment of PVEcho as Docker containers also supports the push for the Controls Team to adopt better fail-over procedures [8]. It ensures that both containers will automatically restart if they are brought down by an internal failure or by failure of another service. This helps to ensure that PVs and alarms are always available and reduces the burden on on-call developers.

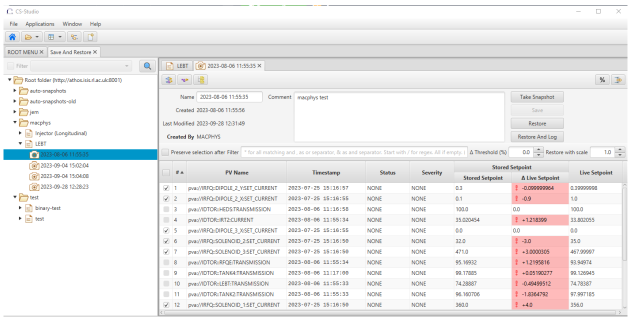
Both services have been deployed and in operational use with minimal intervention or changes since November 2022.

EXAMPLES OF USE

As mentioned in the introduction, the use of bridging software, particularly V2E, has allowed us to make significant progress towards the adoption of EPICS tools, without having ported a significant amount of hardware. This section will outline some of the areas in which PVEcho has allowed us to make progress.

Previous work [8] was completed that reverse engineered the VDraw screens to recreate them as Phoebus screens. Having access to the PVs that would be displayed in these screens has allowed us to validate the conversion and highlight areas where improvements need to be made. Direct comparisons like those shown in Fig. 3 also serves as a visual indication of where there are discrepancies between VSystem channels and their EPICS counterparts to further improve V2E and the auto-conversion.

The development of these screens alongside the deployment of the EPICS Archiver Appliance have allowed us to introduce operators in the control room to the Data Browser, which is already becoming commonplace as a diagnostic tool in machine physics shifts and for post-mortem analysis.



Name 2023-08-06 11:55:35
Created 2023-08-06 11:55:56
Last Modified 2023-09-28 12:31:49
Created By MACPHYS
Comment macphys test

Preserve selection after Filter * for all matching and , as or separator, & as and separator. Start with / for regex. All if empty. (Δ Threshold (%) 0.0 Restore with scale 1.0

	# ▲	PV Name	Timestamp	Status	Severity	Stored Setpoint		Live Setpoint
						Stored Setpoint	Δ Live Setpoint	
✓	1	pva://IRFQ::DIPOLE_2_Y:SET_CURRENT	2023-07-25 15:16:57	NONE	NONE	0.3	! -0.099999964	0.39999998
✓	2	pva://IRFQ::DIPOLE_2_X:SET_CURRENT	2023-07-25 15:16:55	NONE	NONE	0.1	! -0.9	1.0
	3	pva://IDTOR::HEDS:TRANSMISSION	2023-08-06 11:16:58	NONE	NONE	100.0	0.0	100.0
	4	pva://IDTOR::IRT2:CURRENT	2023-08-06 11:55:34	NONE	NONE	35.020454	! +1.218399	33.802055
✓	5	pva://IRFQ::DIPOLE_3_X:SET_CURRENT	2023-07-25 15:16:55	NONE	NONE	0.0	0.0	0.0
✓	6	pva://IRFQ::SOLENOID_2:SET_CURRENT	2023-07-25 15:16:50	NONE	NONE	32.0	! -3.0	35.0
✓	7	pva://IRFQ::SOLENOID_3:SET_CURRENT	2023-07-25 15:16:50	NONE	NONE	471.0	! +3.0000305	467.99997
	8	pva://IDTOR::RFQE:TRANSMISSION	2023-08-06 11:55:34	NONE	NONE	95.16932	! +1.2195816	93.94974
	9	pva://IDTOR::TANK4:TRANSMISSION	2023-08-06 11:17:00	NONE	NONE	99.17885	! +0.05190277	99.126945
	10	pva://IDTOR::LEBT:TRANSMISSION	2023-08-06 11:55:33	NONE	NONE	74.28887	! -0.49499512	74.78387
	11	pva://IDTOR::TANK2:TRANSMISSION	2023-08-06 11:55:33	NONE	NONE	96.160706	! -1.8364792	97.997185
✓	12	pva://IRFQ::SOLENOID_1:SET_CURRENT	2023-07-25 15:16:50	NONE	NONE	360.0	! +4.0	356.0

Figure 6: The first tests of Phoebus' save-and-restore service [20] using values of PVs from V2E.

Likewise, we have been able to make progress towards implementation of Phoebus services such as save-and-restore [20], see Fig. 6, as well as the alarm server [21] using the PVs hosted by V2E. Our goal is to be able to gradually acquaint operators with these tools throughout the transition.

Finally, the availability of VSystem channels as EPICS PVs has allowed us to begin the upgrade of legacy applications designed specifically for VSystem's architecture to use more modern EPICS tooling. Similarly, new applications that interact with the control system are being encouraged to be developed in EPICS where their performance can be validated on the machine using the bridging software while the hardware is still controlled by VSystem.

FUTURE WORK

As is the case for many large-scale software applications, development of the bridging application is continuous. Although most of the behaviour of VSystem has already been implemented in PVEcho, there are still some features that could still be added to match VSystem more closely, for example the ability to dynamically add and remove PVs from the server as Vsystem databases are remade.

Figure 1 highlights the bridge's dependence and links with other services within the stack. While the bridge has been designed to be robust to broken links in this chain, improvements could be made to the communication of these errors to users, for example by placing the PV into an I/O error state when one of the links is broken.

We also anticipate that as our group's understanding of EPICS, its normative types and services evolve, the way we define our PVs will also evolve to more accurately reflect native EPICS structures.

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