DIAMOND'S TRANSITION FROM VME TO FIELDBUS BASED DISTRIBUTED CONTROL

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Abstract

The interface layers of Diamond's accelerator and photon beamline control systems have predominantly been implemented as VME-based systems. Forthcoming control systems, for new photon beamlines, have requirements necessitating a divergence from Diamond's adopted design patterns, including a reduction in available rack space, and we also need to consider the management of hardware obsolescence. To address these issues, a new standard based on PCs and Ethernet field buses to the instrumentation has been defined. This paper will present the new design, how the design transition is being effected and the key benefits to Diamond.

INTRODUCTION

Diamond Light Source is a 3 GeV third-generation light source with a 561 m storage ring (SR), a full-energy booster (BR) and a 100 MeV pre-injector Linac[1]. The photon output is optimised for high brightness from undulators and high flux from multi-pole wigglers. The current operational state includes 19 photon beamlines, with a further three beamlines in an advanced stages of design and construction. A further phase of photon beamlines is now proposed, and subject to funding, detailed design and construction of these 10 beamlines will commence from 2011.

In planning for the next phase of photon beamlines, it was timely to consider the control system architecture applied to future beamlines, associated front ends and experimental stations.

EXISTING CONTROL SYSTEM ARCHITECTURE

Accelerator and beamline control systems use a consistent approach to interface to the hardware, with most equipment interfaced through embedded VME systems. To support the interface requirements of the equipment, a range of I/O modules based on Industrial Pack (IP) modules (ADC, DAC, Serial, DIO) and VME modules (IP carrier, motion, scalar and timing) is used. The field signals are interfaced via either transition modules or front-panel connections. A VME microprocessor (MVME5500) runs VxWorks and EPICS to serve up the control information to client applications. There are in excess of 250 VME-based systems running as part of Diamond's control system[2]. In addition, the electron BPMs run EPICS IOCs directly on the Libera beam processing hardware, and soft IOCs running under Linux on PC hardware concentrate and process data or interface to network attached devices over manufacturer-specific protocols. One anomaly to this approach has been video cameras which have been interfaced to the VME IOC using Firewire and a PMC Firewire adapter located on the VME processor board.

REASON FOR CHANGE

The existing control system architecture has served well for the existing accelerators and beamlines; however it was defined nearly ten years ago, so in the context of the next phase of beamlines the opportunity to reconsider the standards is being taken. In doing so, it is clear that not all the hardware capability of VME is required for beamline control; neither is the use of a hard real-time operating system such as VxWorks. It is also apparent that most I/O functionality required for control of beamline equipment can now be realised through Ethernet-attached I/O. There is also now good infrastructure for developing and managing Linux based EPICS IOCs on a PC architecture.

OUTLINE REQUIREMENTS FOR PHOTON BEAMLINES

In considering the requirements for photon beamline control the following technical systems are identified:

- Motion control
- Vacuum instrumentation and other serial devices
- Video cameras
- Analogue and digital signals
- Programmable logic controllers
- Timing signals

The interface from the IOC to the equipment should make use of the installed network cabling, thereby reducing I/O-specific cabling and giving flexibility in reconfiguration and addition of equipment without the need to pull new cables.

There should be greater partitioning of the IOC functionality by technical area, e.g. motion, camera and vacuum, by running a greater number of EPICS IOC instances, either as separate processes on one Linux system or as single processes, each on a virtualised Linux system. This would minimise the disturbance to beamline operation when making changes that necessitate restarting an IOC.

The I/O associated with the control system should be located close to the equipment being interfaced; i.e. for signals located in experimental and optics hutches, the I/O modules should be co-located in these areas. However, this is constrained by the possibility of radiation-induced damage to I/O in the optics hutches of high energy

(~100keV) beamlines and by the space available in the some beamline hutches.

NEW SOLUTION

Each IOC will run on a 1U Linux PC located within the beamline instrumentation area. This is not regarded as a "soft IOC" as the hardware is connected directly to it. It will probably have several physically separate network connections to support the different systems, so that equipment with limited network stack and CPU capability such as PLCs is not affected by high-data-rate devices such as cameras operating in multicast mode. The structure is shown in Figure 1.

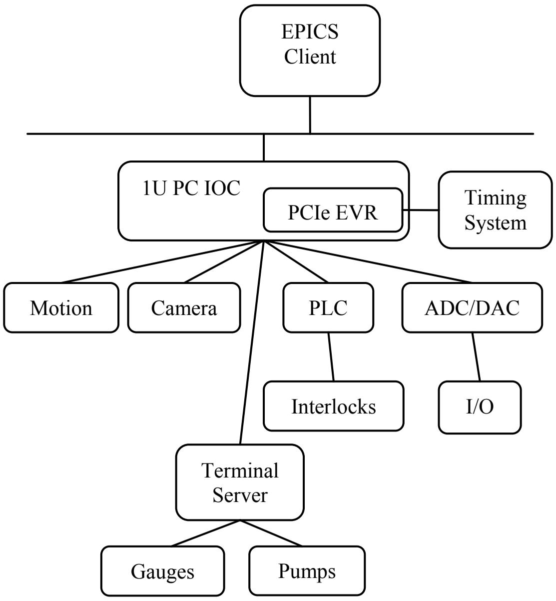

Figure 1: Hardware Architecture

Motion Control

For motion control, a standard based on the Delta Tau Geobrick LV Ethernet-based motor controller is used[3]. This provides 8 axes of motion control and comes complete with amplifiers in a 4U rack-mount box. The existing EPICS motor record software, already in use with older VME hardware, was modified to be compatible with this controller. This was realised by adding an ASYN interpose layer, which provides support for the Delta Tau Ethernet TCP/IP packet structure, and so avoids making changes to the existing PMAC motor controller ASYN driver.

Vacuum Instrumentation and other Serial Devices

Vacuum instrumentation (Gauges and Pump Controllers) and other serial devices will be interfaced through RS232, RS422 or RS485 serial connections. These will connect to a terminal server located in the instrumentation rack and the terminal server via Ethernet to the IOC. On the IOC most serial devices are handled by the EPICS Stream Device module communicating to the serial interface over virtual serial connections to the terminal server.

Cameras on Ethernet

New diagnostic applications will use a range of GigE cameras from AVT (formerly Prosilica).

A video server will run an EPICS IOC using areaDetector[4] to control, process and store images from up to 10 cameras and ffmpegServer[5] for visualisation. AreaDetector is a modular system of EPICS drivers and plug-ins that can be "rewired" at run time, allowing a flexible image processing chain to be set up. Plug-ins for controlling the camera, providing statistics on the images that are produced, filtering them and writing them to disk are included with areaDetector. FfmpegServer is a Diamond-produced plug-in that compresses a stream of images to mjpg and serves them over http.

Programmable Logic Controllers

Interlocking and protection of equipment is realised in Omron CJ1 PLCs. These will be interfaced to the IOC using Ethernet and the FINS[6] protocol over UDP. An EPICS driver has been developed and provides direct read/write access to each PLC's I/O register and memory areas.

The Omron CJ PLC will optionally use remote I/O modules called SmartSlice[7] which will be located in the beamline optics and experiment hutches. The SmartSlice remote I/O comprises a Communications Unit and a number of I/O Units providing digital I/O, analogue I/O, temperature, counter and positioning interfaces.

The SmartSlice I/O Units communicate with the host PLC over a private Ethernet connection running the PROFINET protocol**.** PROFINET[8] provides flexibility so that it is simple to configure additional I/O modules. The interface is realised over standard Ethernet connections.

ADCs DACs and DIO

To interface ADCs, DACs and digital I/O, a range of I/O modules from Beckhoff Automation (Verl, Germany) has been selected. These use EtherCAT[9], an industrial Ethernet-based fieldbus system. This I/O will be used for all non-interlocking type applications, and provides lower latency from the plant to the IOC than the PLC solution. It further minimises the number of I/O points in the PLC-based interlocking system and so minimises the need for changes to the PLC which necessitate revalidation of the interlock logic.

The EtherCAT protocol provides low-latency data transfer from the I/O modules into the host computer. It operates on the principle of a master that communicates with slaves using EtherCAT telegrams that are passed around each node and back to the master. The EtherCAT master uses standard Ethernet controller hardware and a software implementation of the EtherCAT functionality, whilst the slaves use a custom slave controller.

The custom interface implements a Fieldbus Memory Management Unit (FMMU), which allows the mapping of logical addresses in the telegram to physical ones within the slave. This processing occurs on the fly as one slave passes the telegram through to the next slave, introducing a delay of a few nanoseconds. Slaves also automatically close a communication ring when the outgoing Ethernet link (downstream section) is not connected, by returning the telegram to the master back through the chain of slaves.

The telegram structure allows several slaves to be addressed in a single Ethernet frame. This characteristic significantly reduces the overhead in comparison to other Ethernet fieldbus protocols, and is well suited to address devices that may have a payload of only a few bytes, such as digital I/O devices that are typical in industrial automation.

Although the protocol will operate with other Ethernet-based services and protocols on the same physical network, the proposed Diamond Remote I/O solution will adopt strict segregation of the EtherCAT bus.

Because we are using Linux, the hardware supported is limited to Realtek and Intel cards, plus a 'generic' interface.

Timing Signals

The Diamond timing system is applied across the accelerators and beamlines[10]. On the beamlines it is used to decode orbit and bunch clocks to enable synchronisation of experiments to the stored beam structure. It provides gating signals which at injection, during top-up operation, are used by beamline detectors to mask out the stored beam disturbance. The timing system also provides time stamps for EPICS record processing. To support this functionality in the new architecture, it is envisaged that a PCIe version of the Event Receiver module will be developed. This will make the time stamp information available in the PC-based IOC and will bring out the decoded signals on a 1U interface panel.

SUMMARY OF PROGRESS TO DATE

Ethernet-based motion control subsystems are already implemented and deployed on a number of beamlines connected to both PC and VME IOCs. They have proved to provide effective control of stepper and servo motor systems, e.g. monochromators, slits, mirrors etc. Remote diagnostics and configuration are also proving to be very valuable.

Similarly interfacing a range of instruments over terminal servers is also actively being used and makes use of already developed Streams support modules.

The FINS interface to the Omron PLC has been implemented and deployed to integrate a single PLC controlling LN2 distribution. The design of standard remote I/O modules has also been undertaken. Given the risk of possible radiation damage, SmartSlice remote I/O units have been in soak-test for the past two months in one of Diamond's optics hutches. The implementation of SmartSlice systems is being planned for forthcoming beamline control and front-end equipment protection systems.

The EtherCAT based remote I/O has been through initial evaluation and testing with a Linux x86 PC as a host. Initial tests have been performed using an Intel E1000 controller on a standard RHEL5 dual-core Intel Pentium 4 Xeon PC. A user-space polling process, fully using one of the two available cores, was able to reproduce a pulse read from an ADC and to drive a digital output with a delay of 200 microseconds. Further effort is planned to develop EPICS device support for the various EtherCAT I/O modules to be used on Diamond.

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