UPGRADE FROM ADCs WITH CENTRALLY SCHEDULED TRIGGERS TO CONTINUALLY TRIGGERED WAVEFORM DIGITIZERS*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) control system includes many data channels that are timed and flavored, i.e., users can specify the species of beam and time within the beam pulse at which data are reported. The legacy LANSCE control system accomplished this task by queuing up application software-initiated requests and scheduling Analog to Digital Converter (ADC) readout with custom programmable time-delay gated and multiplexed Remote Information and Control Equipment (RICE). This year we upgraded this system to a new Experimental Physics and Industrial Control System (EPICS) system that includes signal dedicated waveform digitizer. An appropriate subset of the data is then returned as specified by each client. This is made possible by improvements to EPICS software, a Commercial Off-The-Shelf (COTS) Field Programmable Gate Array (FPGA) Mezzanine Card (FMC) based ADC and a COTS VPX FPGA card with EPICS embedded on a soft-core processor. This year we upgraded over 1200 waveform channels from RICE to the new TDAQ (Timed/flavored Data Acquisition) system.

BACKGROUND

The LANSCE Accelerator was designed and built with some unusual capabilities. LANSCE is a 120 Hz pulsed linear accelerator that can deliver beam to 6 different experimental areas. H^+ and H^- ions can be accelerated simultaneously and delivered to two different areas on the same beam pulse. Within a 1 second “super-cycle” beam can be delivered to 5 different experimental areas. In addition, the beam energy can be controlled on a pulse-by pulse basis allowing for up to 3 different H- beam energies within 1 second (delivered to different experimental areas). The original RICE control system at LANSCE was designed to support simultaneous data collection from multiple locations along the accelerator at a specified time within a beam pulse, and with a specified flavor [1, 2]. The RICE system allowed flavoring based on the presence or absence of any of 96 gates. The goal was to upgrade the existing RICE system to a new Timed/flavored Data Acquisition system (TDAQ) [3].

Flavor

Flavor refers to which beam areas will receive beam and whether RF is configured to accelerate beam. It is important to be able to measure beam delivered to a particular experimental area, because beam parameters can differ significantly on a pulse-to-pulse basis depending on the configuration. Flavor must not only refer to the area of delivery, but also the combination of areas because on pulses where H+ and H- beams coexist beam loading effects may be different than when one beam species is delivered alone.

At LANSCE, the flavor specification allows for each flavor element to be specified as required to be present, required to be absent, or not listed (do not care). The new system currently has only 11 active flavor elements resulting in 3^{11} possible flavor specifications. Only a small subset of these flavor specifications will be useful, but an important consideration is that the set of useful combinations cannot be known a-priori and is instead determined based on the immediate daily demands of our operations staff as driven by the flexible reconfiguration of LANSCE experimental stations.

Timing

In the RICE system timing for data collection could be specified to be a time relative to the leading or trailing edge of any gate in the timing system and could encompass any time withing the 8.33 ms cycle. Time could be specified in microseconds but was only accurate to +/- 1.5 µs. Recognizing that beam is only available for a small subset of the 8.33 ms cycle, we limited the new system to 4 ms of data collection per cycle.

RICE Implementation

In the RICE system, a central computer handled all data collection from remote instrumentation. Multi-signal vectored reads could be performed simultaneously across more than 50 different locations. However, a given input could only be measured at 120 Hz once per beam cycle, and only one vector read (of a single input at each location) could be performed each cycle. A sophisticated scheduling program kept track of which measurements were requested and would fill them with recently collected data or queue a new data take. Typically, data could be obtained with a delay of about 5 seconds. During tuning the data collection queue would sometime be as much as 60 deep, resulting in a delay of one minute to collect a single point from a flavor that is only scheduled to occur once per second. For example, it was therefore important to limit the number of simultaneous data consumers during emittance measurements.

TDAQ IMPLEMENTATION

The new system uses independent EPICS IOCs (Input/Output Controllers) with signal-dedicated waveform digitizers. Each TDAQ system operates independently and can simultaneously sample 16 inputs. At 120 Hz, a full 4 ms of data at ~1 µs intervals is available for each input. Client applications can then specify a subscription update

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filter that includes the time range and flavor of data to be reported. A decimation algorithm is used to limit the flavored subscription update rate to a maximum of 4 Hz. The same decimation algorithm is used in all TDAQ systems, so for a given flavor specification multi-IOC data comes from the exact same 4 (or fewer) cycles each second. Modifications were made to EPICS to be able to tag the in-flight data with timing and flavoring information and support the necessary filter specifications [4]. The EPICS IOCs receive time-stamp information along with the flavor map over a dedicated timing-system-synchronized fiber link at 120 Hz.

Hardware

A COTS 125 MHz 14-bit 16-channel FMC ADC is used to sample waveform data. The FMC board is connected to a COTS (Bittware) VPX Digital Signal Processor (DSP) card that embeds a soft-core processor (Altera NIOS-II) and in-house developed digital signal processing within a Stratix IV FPGA. A hybrid VPX/cPCI (compact Peripheral Component Interconnect) crate can hold multiple DSP cards, an Ethernet/PCIe switch card, a compact PCI event receiver card (for timing), and an in-house developed analog signal conditioning board [5]. A COTS PCI/cPCI monarch bridge board is used to communicate with the compact PCI system. We shared the same core components with Beam Position and Phase Monitoring hardware that differs only in the choice of FMC digitizer board and analog signal conditioning board as well as the FPGA signal processing algorithms. Analog signal conditioning was required because the ADC expects a 2 V-pp signal and has a 50 Ohm input impedance, but many signals were not impedance matched and levels ranged from 100 mV to 10 V. On the Bittware board a Stratix III (aka FINe) FPGA chip runs an additional EPICS soft-core IOC that is dedicated for configuring/booting the the larger Atlantis Stratix IV FPGA Chip along with implementing network remote commanded restart.

Software

The FPGA digital signal processing samples the data at 125 MHz and implements a decimating cascaded integrator-comb filter with finite impulse response compensation to give a produced 976 kHz data rate with enhanced precision. FPGA-accelerated piecewise linear scaling of all waveform elements is configured based on EPICS database breaktables. Filtering functions are flexibly performed in Lua language code that calls C functions. Each EPICS waveformX record supports a default Lua filter expression, used to specify a LANSCE-specific flavor, to be used if none is specified by the EPICS client in a PV name postfix expression. The EPICS IOC uses the Real-Time Executive for Multiprocessor Systems (RTEMS) operating system on the soft-core (implemented in the FPGA fabric) NIOS-II processor. The NIOS-II processor runs at ~200 MHz and currently has no hardware floating point unit instantiated. The RTEMS software includes support for both PCI Express root-port and end-point configurations so multiple DSP boards can be installed in a single crate. The EPICS software uses C++ smart pointers to minimize copying of waveform and timing data. We modified the library called by control room applications when requesting timed/flavored data from the legacy RICE system to alternatively formulate the requests in the new Lua language expression syntax as a postfix to the EPICS process variable name and retrieve the data. This library was also modified to assemble vectored data from multiple IOCs by correlating the timestamps from multiple independent arrival time channel subscription updates rather than submit a vector request to the legacy RICE system.

DEPLOYMENT

The TDAQ system is a functional upgrade for the RICE system and provides higher bandwidth and precision waveform data with reduced update arrival latency. This greatly improves the efficiency of certain tuning operations. This year we replaced approximately 700 RICE inputs using 62 TDAQ VPX board embedded systems.

Due to rapid deployment a few issues were observed with correctly setting scaling parameters. The most significant issue was due to increased demand for data. The system has higher input bandwidth, and so data were noisier than users expected (the RICE system had only 50 kHz bandwidth). This meant that the legacy RICE practice of observing a single time-sampled signal default value became obsolete, and users requested that 20 adjacent time samples be averaged. Users are requesting certain typical flavors that were previously available, but now with a time range specification. Also, archivers were used to record this data. We updated the systems supplying typical default flavors to average 20 adjacent points and implemented that on a layered EPICS soft IOC to limit connections to each individual IOC for typical flavor/time specifications. With a large number of client subscriptions the Central Processing Unit usage was saturating and limiting the ability to provide data to additional clients. We considered decreasing the data rate as 100 kHz would still be an improvement over RICE, and possibly limiting the sample time to 2 ms (this covers the region of interest for nearly all applications). The biggest performance issue appears not to be with the volume of data, but with processing all of the client-requested filters on a system running at 120 Hz as data come in to decide if it should be sent to a particular client or not. Implementing the averaging for the most common channel subscriptions on a soft IOC was enough to mitigate the issue. There may be some optimizations that can improve the acceptable number of simultaneous filters in the future. The beam physicists noted that optimizing current transmission via steering magnets takes less than 10 minutes this year, while in the past it could take up to one hour.

Another issue we encountered was that RTEMS 4 only supports NFS (network file system) version 2, and newer files servers no longer support this protocol. The FTP file system support on RTEMS was not acceptable, although it works reasonably well on our older VxWorks systems. This is an issue we will need to address in the future.

CONCLUSION

The RICE timed/flavored data features were successfully upgraded to an EPICS based system. The new system is more flexible with improved multi-element capture, precision and bandwidth, as well as the ability to implement arbitrary Lua language expression subscription update filters as desired when clients connect. Vector data is significantly more flexible as the RICE system required vector channels to use the same physical input on all modules. The new system can correlate a set of signals, and all inputs are sampled simultaneously. Additionally, waveform data can be requested allowing for measurements of beam from the start of the pulse to the end of the pulse from a signal cycle, in contrast to the legacy RICE pseudo waveforms assembled using time samples from different beam pulses. The more consistent and rapid data collection latency may improve the feasibility of algorithm-based optimization and automated tuning techniques.

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