ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA023

APPLICATIONS OF AN EPICS EMBEDDED AND CREDIT-CARD SIZED WAVEFORM ACQUISITION

Y. S. Cheng†, D. Lee, C. Y. Liao, C. Y. Wu, K. H. Hu, K. T. Hsu
National Synchrotron Radiation Research Center, Hsinchu, Taiwan

Abstract

To eliminate long distance cabling for improving signal quality, the remote waveform access supports have been developed for the TPS (Taiwan Photon Source) and TLS (Taiwan Light Source) control systems for routine operation. The previous mechanism was that a dedicated EPICS IOC has been used to communicate with the present Ethernet-based oscilloscopes to acquire each waveform data. To obtain higher reliability operation and low power consumption, the FPGA and SoC (System-on-Chip) based waveform acquisition which embedded an EPICS IOC has been adopted to capture the waveform signals and process to the EPICS PVs (Process Variables). According to specific purposes use, the different graphical applications have been designed and integrated into the existing operation interfaces. These are convenient to observe waveform status and to analyse the caught data on the control consoles. The efforts are described at this paper.

INTRODUCTION

TPS is a new and highly bright synchrotron light source constructed at National Synchrotron Radiation Research Center (NSRRC) at Taiwan. It consists of a 150 MeV electron linear accelerator, a booster synchrotron, a 3 GeV storage ring and experimental beam lines. Civil construction began in the first quarter of 2010 and was completed in the first half of 2013. Installation and integration of the accelerator system began later in 2013. The control system environment was ready by mid of 2014 to support commissioning and final subsystem integration without the beam. Commissioning with the beam was successful in December 2014. User service with 400 mA top-up routine operation was kicked off since 2016.

TLS is a third generation of synchrotron light source which built at the NSRRC site, and it has been operated since 1993. The TLS consists of a 50 MeV electron linear accelerator, a booster synchrotron, and a 1.5 GeV storage ring with 360 mA top-up injection mode. The TLS Control system is a proprietary design [1]. It consists of console level workstations and VME based intelligent local controller (ILC) to interface with subsystems. Hardware and software on console level workstation change several times due to evolution of fast evolution of computer technology.

EPICS (Experimental Physics and Industrial Control System) were chosen as control system framework for the TPS and had been integrated and commissioned [2]. On the other hand, in order to adopt newer technology and re-use expertise of manpower, the upgrade and maintenance for TLS control system have been decided to employ the EPICS as its framework. Thus new installed and rejuvenated sub-systems have operated at the EPICS control environment. Mixed existing TLS control system and EPICS framework were proofed without difficult problems.

Many waveforms in synchrotron light sources are necessary to monitor during routine operation, and especially include current waveforms of pulsed magnet power supplies (septa/kickers), waveforms of klystron current and voltage, waveforms of LINAC RF power, etc. Moreover remote waveform access supports have been widely utilized to eliminate long distance cabling for improving signal quality. Preliminary solution of remote waveform access support is that a dedicated EPICS IOC (Input Output Controller) is built to interface with Ethernet-compliant oscilloscopes for capturing and publishing real-time waveform data [3].

Recently, an advanced solution of remote waveform access support is adopting a credit-card sized waveform acquisition. The major benefits of this credit-card sized waveform acquisition are EPICS embedded, better resolution, better stability, and lower power consumption. The efforts of applying a new credit-card sized waveform acquisition on the TPS and TLS control systems are summarized in the following paragraphs.

CREDIT-CARD SIZED WAVEFORM ACQUISITION

A new credit-card sized waveform acquisition has been developed to be as remote waveform access support for observing necessary waveforms during routine operation. This waveform acquisition module is a FPGA-based (Field Programmable Gate Array) hardware architecture, named "Red Pitaya" [4], which is an open-source hardware formed into a credit-card sized layout. It equips one dual-core processor, one editable FPGA-based SoC, ADC (Analog-to-Digital Converter) of two-channel-input, external trigger functionality, DI/DO (Digital Input Output) pins, one micro-SD storage, and one gigabit Ethernet port. The main specification of hardware components is shown as Table 1. This acquisition module has 7.5 Watt power consumption, and is much lower than power consumption of traditional oscilloscope. This acquisition module internally supports Linux operation system which installed into micro-SD card for setting up related software packages, compiled FPGA codes and application programs. According to the test of real signal inputs, this waveform acquisition module can be equivalently employed to replace several traditional oscilloscopes for being long-term waveform observation.

† E-mail: cheng.ys@nsrrc.org.tw

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA023

Table 1: Specification of Acquisition Hardware

Component	Specification
Processor	Dual Core ARM Cortex A9
FPGA	Xilinx Zynq 7010 SoC
RAM	512 MB
RF Input	Channel: 2
	Sample Rate 125 MS/s
	ADC Resolution: 14 bit
	Full Scale: +-1 V, +-20 V
Bandwidth	50 Mhz
Memory Depth	16 K Samples
Ethernet	1 GigE
Storage	Micro-SD up to 32 GB
Power Connector	Micro-USB, 5 V
Power Consumption	7.5 Watt

SYSTEM ARCHITECTURE

Two or three parts of acquisition modules have been combined into one box for the remote waveform access support as shown in Fig. 1. The front panel of box is for signal inputs and external trigger, and back panel is for power and control network connections. The custom-made attenuators with frequency compensation have been also designed and implemented to meet various signal type, such as 50 Ohm, 1 MOhm, high input voltage, etc.

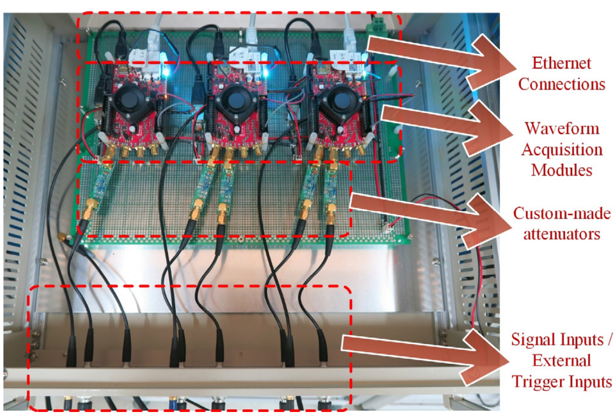

Figure 1: Photo of an assembled box with three waveform acquisition modules.

These assembled waveform acquisition boxes have been mounted at the equipment areas of sub-systems, and integrated into existing control environment according to the different purposes. The conceptual system architecture of new waveform acquisition is illustrated as Fig. 2. New waveform acquisition module is as a standalone EPICS IOC which connects to the control network. The captured waveform data are calculated in the EPICS IOC, and the PVs of processed waveform data are published. These waveform PVs are launched to the existing graphical user interfaces according to various functionality, such as for pulsed magnet power supplies, klystron current and voltage, LINAC RF power, etc.

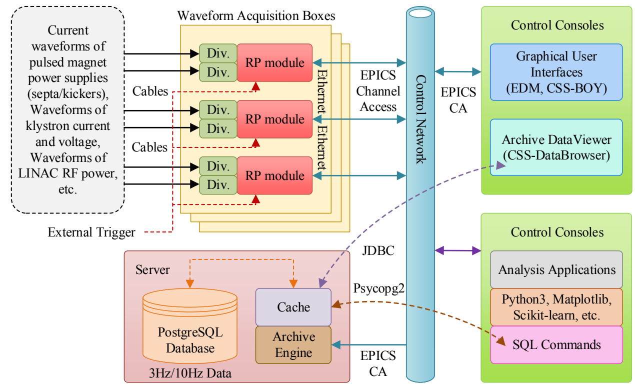

Figure 2: System architecture with credit-card sized waveform acquisition systems.

In addition, each waveform data is also extracted several characteristic parameters in the EPICS IOC to learn its variation on injection of 3 Hz or 10 Hz. These parameters have been archived into the relational database for long-term analysis usage. Client users can use the specific toolkits to retrieve the data from database. In order to analyse the archived data, the analysis applications have been developed to make the statistics. It is convenient to observe the long-term variation and stability.

An EPICS support has been built into a credit-card sized waveform acquisition module which operates the Linux operation system, and the compiled FPGA image file has been loaded to communicate with the device support via API library. One of EPICS database records is the waveform record which stored data array acquired from the acquisition device. Related record supports were created with a link to the device supports, and especially the waveform records are made basis array data processing. Then waveform data are extracted key characteristic parameters, such as peak amplitude and peak time location, to monitor real-time variation. Furthermore complex array calculation is done by the Python program in the IOC. The software block diagram for establishing EPICS support of waveform acquisition system is shown as Fig. 3. Client users observe and analyse captured waveforms by use of EPICS CA (Channel Access) mechanism easily.

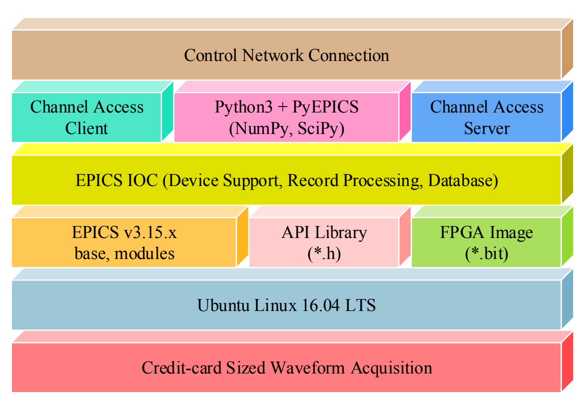

Figure 3: Software block diagram of EPICS embedded and credit-card sized waveform acquisition systems.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA023

A new EPICS embedded and credit-card sized waveform acquisition has been already implemented and employed on the TPS and TLS control systems more than half year. At the beginning, this system has applied on the sub-system of TPS pulsed magnet power supplies for replacing broken Ethernet-compliant oscilloscope. These system are more useful to monitor real-time current waveforms on each beam injection of 3 Hz, and are easily for tuning parameters of pulsed magnet power supplies. Furthermore, this acquisition system has been also utilized to observe the major waveforms of TLS booster ring for optimized parameters adjustment, such as kickers, klystron current and klystron voltage. The GUIs of these two sub-systems are shown in Fig. 4.

(a)

(b)

Figure 4: Several credit-card sized waveform acquisitions employed and integrated into the sub-systems of TPS and TLS: (a) GUI of TPS pulsed magnets power supplies; (b) waveform display page of TLS booster ring.

AUTOMATED ANALYSIS WITH MACHINE LEARNING ALGORITHM

The characteristic parameters of current waveforms of pulsed magnets power supplies which captured from the credit-card sized acquisition have been drawn and recorded into database for a long time. The amount of archived parameters are huge from routine operation with 3 Hz/10 Hz injection mode, then display page of retrieved data from database is shown at Fig. 5. These data can be the chance of judging which time is abnormal status manually. To simplify the mission, an automated analysis method to judge abnormal status will be more essential.

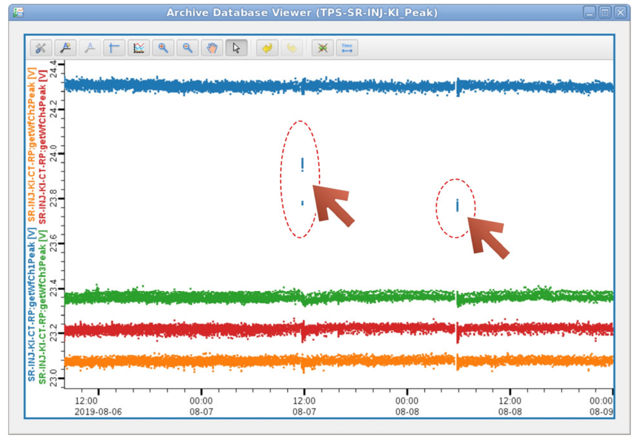

Figure 5: Archive database viewer with dot display for observing the variation of waveform peak amplitude of TPS storage ring kickers, and occurred a little abnormal status (K1)(red line).

Moreover the machine learning is the scientific study of algorithms and statistical models that computer systems use to perform a specific task without using explicit instructions, relying on patterns and inference instead. It is seen as a subset of artificial intelligence. Machine learning algorithms build a mathematical model based on training data, in order to make predictions or decisions without being explicitly programmed to perform the task [5]. Thus one of the machine learning algorithms can be suited for automatically judging abnormal status of captured current waveforms via processed sample data.

The "Decision Tree" method is a supervised learning [6][7] from machine learning algorithm. The decision tree algorithm can be applied for building an automatic mechanism of judging abnormal status, and the functional block diagram is shown in Fig. 6. Amount of archived data is retrieved and divided into two parts; one is used for training, the other is used for evaluating the model. The decision tree model is generated based on critical parameters with training data, then the model is verified via testing data repeatedly. After completing the evaluated model, new captured data can be approximately predicted the result of the normal or abnormal status. The accuracy with new advanced model will be raised through more and more new acquired data to achieve fully automated analysis.

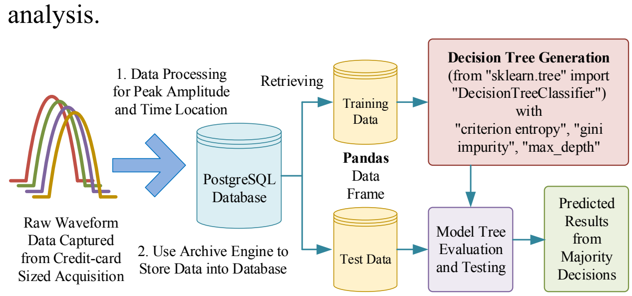

Figure 6: Functional block diagram of building a decision tree mechanism for training amount of archived data to judge abnormal status automatically.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA023

SUMMARY

To eliminate long distance cabling for improving signal quality, remote waveform access supports are necessary to be developed. A new EPICS embedded and credit-card sized waveform acquisition system has been implemented and applied on the TPS and TLS control systems. This is successful to replace broken Ethernet-based oscilloscopes which interfaced with a dedicated EPICS IOC. The published waveform PVs are smoothly integrated into the existing GUIs at the mean while. The analysis applications are designed and enhanced continually, and hope to provide automated analysis service in the future. This new waveform acquisition system will accomplish better diagnostic toolkit and highly reliable routine operation.

REFERENCES

[1] G. J. Jan *et al.*, "Computer Control and Instrumentation System at the SRRC", *Nucl. Instrum. Methods Phys. Res.*, Sect. A, vol. 352, 1994, pp. 33-39.

[2] Y.-S. Cheng *et al.*, "Status of the TPS Control System", in *Proc. 12th International Workshop on Personal Computers and Particle Accelerator Controls (PCaPAC'18)*, Hsinchu City, Taiwan, Oct. 2018, pp. 6-10. doi:10.18429/JACoW-PCaPAC2018-WEC2

[3] Y.-S. Cheng, K. T. Hsu, K. H. Hu, C. Y. Liao, and C. Y. Wu, "Remote Waveform Access Supports with EPICS for TPS and TLS Control Systems", in *Proc. 12th International Workshop on Personal Computers and Particle Accelerator Controls (PCaPAC'18)*, Hsinchu City, Taiwan, Oct. 2018, pp. 198-200. doi:10.18429/JACoW-PCaPAC2018-THP16

[4] Red Pitaya website, https://www.redpitaya.com

[5] C. Bishop, *Pattern Recognition and Machine Learning*, Springer, 2006, ISBN: 978-0-387-31073-2.

[6] S. J. Russell *et al.*, A*rtificial Intelligence: A Modern Approach*, Prentice Hall, 2009, ISBN: 0-13-604259-7.

[7] J. R. Quinlan, "Simplifying decision trees", *J. Human-Computer Studies*, vol. 51, Issue 2, Aug. 1999, pp. 497-510.