A PROTOTYPE DATA ACQUISITION SYSTEM OF ABNORMAL RF WAVEFORM AT SACLA

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Abstract

We developed a data acquisition (DAQ) system for abnormal RF waveforms at the X-ray Free Electron Laser facility, the SPring-8 Angstrom Compact Free Electron Laser (SACLA). When a problem occurs, we must diagnose the source quickly. For this purpose, we developed a system that captures an abnormal RF waveform when a problem occurs in an RF system, and stores the waveform data in a database. The system consists of the VME systems, a waveform server, and a NoSQL database system, Apache Cassandra. When the VME system detects an abnormal RF waveform, it collects all related waveforms of the same shot. The waveforms are stored in Cassandra through the waveform server with shared memory as cache to complement Cassandra's eventual consistency model. We constructed a prototype DAQ system with a minimum configuration and checked its performance. In this paper, we report the scheme of the waveform DAQ system and the test results.

INTRODUCTION

SACLA has been operating for user experiments since March 2012. To maintain the scheduled user time as much as possible, we must reduce down time due to failure. To diagnose a failure source, it is quite helpful to collect the data of many accelerator components.

We have been installing two types of database systems since the beginning of commissioning. One is a data logging system with a cycle of several seconds, which provides diagnosis for slow fluctuation, such as environmental temperatures, the flow of cooling water, and the receiving voltage from the electric cubicles. The data are stored in a Sybase relational database management system [1]. Another database system is an event-synchronized data acquisition (sync-DAQ) system that collects beam currents, beam positions, and the phase and amplitude of the RF cavity pickup signals in synchronization with the beam operation cycle at the current maximum of 60 Hz. Shot-by-shot data are tagged with a master trigger number to identify the the beam shot to which the data belong. The master trigger number is generated by counting a master trigger signal distributed from the master oscillator system. Shot-by-shot data with trigger numbers are stored in the MySQL relational database management system [2]. In addition, the DAQ system collects RF waveform data every 10 minutes. At the collection, however, it is difficult to catch an abnormal RF waveform from a rare failure event that may occur only a few times a day. If we can catch the abnormal RF waveform, it is very helpful to analyze the phenomenon, because it has more information than point data, which is sampled from a waveform. Therefore, we developed a DAQ system to capture abnormal RF waveforms, an abnormal WFM-DAQ system. As a first step, we constructed a prototype system at a test stand.

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LOW-LEVEL RF CONTROL SYSTEM

The linear accelerator of the SACLA comprises an electric gun, a 238-, 476-, 1428-MHz multi-sub harmonic bunching and accelerating system as an injector, eight S-band accelerating structures, and 128 C-band accelerating structures and in-vacuum undulators beamlines [3]. The low-level RF (LLRF) system controls the 74 RF units in the SACLA accelerator. A VME system, used at each RF unit, consists of a CPU, a trigger delay unit (TDU), a DAC and three ADC boards. The TDU board delivers the delayed trigger signal to the ADC and DAC boards, and generates the master trigger number by counting the master triggers. The ADC and DAC boards running 238-MHz clock detect the phase and amplitude signals generated by klystron, and generate signals of the IQ modulator for klystron input.

In the VME system, many processes are in operation including an equipment management process (EM), a data logging process, a Sync-DAQ process (SYNQDAQ-EMA) in synchronization with the beam operation cycle, and a feedback process (PID-EMA) for the stabilization of the phase and amplitude of the RF cavity with 100-ms sampling intervals [4].

SCHEME OF ABNORMAL WFM-DAQ SYSTEM

The abnormal WFM-DAQ system consists of a VME system, a waveform server, and Apache Cassandra, which is a key-value database system. Figure 1 shows a diagram of the abnormal WFM-DAQ system.

Detection of an Abnormal Waveform and Transfer of Data

The ADC board has four channels and four-memory banks that can store 512 waveform data in synchronization with a trigger signal. In addition, the ADC board generates an interrupt signal when it detects an abnormal waveform by comparing it with a reference waveform. When the sampled waveform exceeds a defined tolerance

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of the reference waveform, the board sends an interrupt signal to the CPU board [5, 6].

We developed an event-driven process, ALM-EMA that detects an abnormal waveform, and collects all related waveforms at the same shot [7, 8]. ALM-EMA treats 12 ADC channels. Each channel is assigned a human-readable signal name, such as "xfel_llrf_cb01_1_iq_acc_1_dload_ta_q/waveform_err". To prevent unnecessary abnormal detection at a start-up, an operator issues a start command of abnormal detection from the operation GUI with a stable RF condition. When ALM-EMA receives a start command, the process sets a normal waveform as a reference waveform and transfers the reference waveform to Cassandra through a waveform server. When an ADC board detects an abnormal waveform, the board issues an interrupt signal to a CPU. ALM-EMA performs the following actions.

- By receiving the interrupt signal, ALM-EMA disables abnormal detection and takes meta-information, such as a timestamp, master trigger number, bank number to which the waveform data are written, and the address point of the memory area to which the abnormal waveform data are written in the bank.
- ALM-EMA makes all ADC channels switch the bank to preserve the sampled waveform data. The process captures not only the abnormal waveform but also previous waveforms and following waveforms of the abnormal one on memory.
- ALM-EMA sends each waveform with meta-information to a waveform server and receives a reply message from the server.
- ALM-EMA enables the abnormal detection and waits until receiving a start command from the operation GUI.

We defined three types of messages for transfer to the waveform server. One is a signal registration message including a signal name, sampling number, and one point data size of waveform. Another is a waveform data transfer message, including a signal name, a timestamp, master trigger number, error flag that indicates whether the waveform is normal or abnormal, and waveform data. The third message type is a replay message from the waveform server.

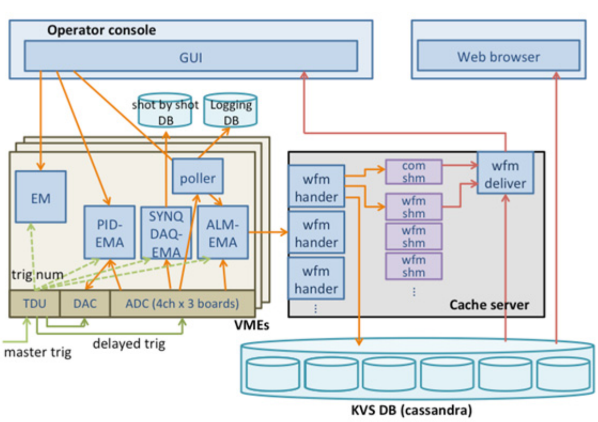


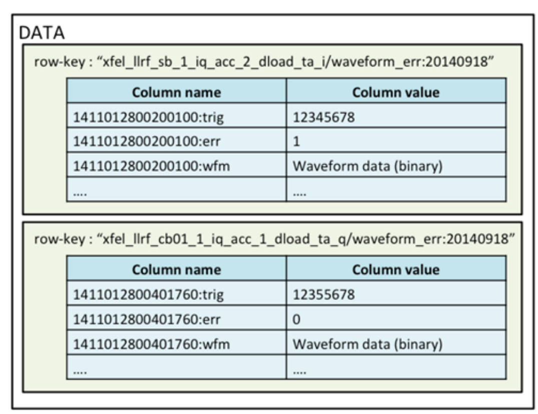
Figure 1: A diagram of abnormal waveform DAQ system.

A Database System

Cassandra has features such as a column-oriented data structure, high write performance, fault tolerance, and no single point of failure (SPOF). It is especially easy to increase total throughput by adding more nodes to the system [9]. We designed the data structure to efficiently handle time series, trigger numbers and error flags. Figure 2 shows the data structure. One row-key provides the information of one day's signal. The row-key name is formed from a signal name in addition to a date string and contains collections of columns. One column consists of a name and a value. A name is formed from the timestamp in addition to a key word such as "trig", "err", or "wfm".

Cassandra is possible to elicit high performance by parallel programming. However, the parallel programming requires many steps in some programming languages. We developed a Web service framework, implementing a simple MapReduce model for reading waveform data by the parallel processing from Cassandra [9].

Cassandra can construct multi node clustering to achieve a redundant and load-balancing system. From our study of the Cassandra cluster, when the data are taken from a cluster with six nodes and a replication factor of three, we found that the time required for guaranteeing consistency is as much as 1-s [10]. To prevent this inconsistency, we developed a cache server mechanism.


DATA

row-key : "xfel_llrf_sb_1_iq_acc_2_dload_ta_i/waveform_err:20140918"

Column name	Column value
1411012800200100:trig	12345678
1411012800200100:err	1
1411012800200100:wfm	Waveform data (binary)
....	....

row-key : "xfel_llrf_cb01_1_iq_acc_1_dload_ta_q/waveform_err:20140918"

Column name	Column value
1411012800401760:trig	12355678
1411012800401760:err	0
1411012800401760:wfm	Waveform data (binary)
....	....

Figure 2: Cassandra's data structure.

Waveform Server

A waveform server consists of a waveform handling process (wfm-handler) and a waveform readout process (wfm-deliver) with two kinds of shared memory as a cache. A wfm-hanlder writes waveform data received from ALM-EMAs to shared memory and Cassandra in parallel. We can flexibly increase the number of the wfm-hander to distribute accesses from 74 LLRF VME systems. When a wfm-handler receives a signal registration message, the process writes signal information on shared memory (comshm). All signal information is consolidated on comshm. When a wfm-handler receives waveform

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data, the process writes the data on shared memory (wfmshm) for waveform created each signal. wfmshm keeps data for 2-s from the current time to complement Cassandra's eventual consistency.

A wfm-deliver takes waveform data from wfmshm or Cassandra in accordance with a timestamp that the operation GUI requires, and transfers the data to the operation GUI.

TEST

We constructed a prototype system with a minimum configuration to ensure the performance of the LLRF VME system, a waveform server, and Cassandra at an RF test stand. The VME system was set up with the same configuration of LLRF control of SACLA. The Cassandra cluster had three nodes and a replication factor of two.

It took 1.1-ms to take 16KB of waveform data from an ADC channel at our measurement. The round trip time to transfer waveform data from the VME to Cassandra through a waveform server and to the receive reply message was 10-ms. To prevent blocking VMEbus access from PID-EMA, ALM-EMA took each waveform data at a 500-ms interval. The CPU load of ALM-EMA was less than 1%. Therefore ALM-EMA does not prevent other processes.

Figure 3 shows an example of an abnormal waveform detection of a C-band cavity with a 30-Hz operation cycle at the RF test stand. The WFM-DAQ system detected an abnormal waveform shown by the red line at event number 714639. The previous waveform (event number = 714638) and the following waveform (event number = 714640) were almost consistent with the reference waveform. These shot-by-shot data were stored in Cassandra. At that time, worsening of the vacuum caused an abnormal waveform of the klystron forward RF signal. The prototype WFM-DAQ system was able to capture the sudden abnormality.

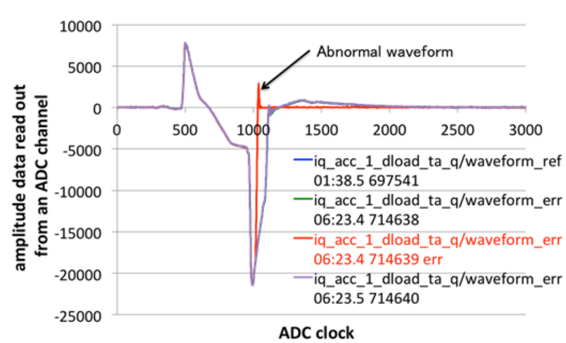

Figure 3: An example of an abnormal waveform detection at the test stand. The red line is an abnormal waveform, and the blue line shows a reference waveform. The green and purple lines are the previous and following waveforms of the abnormal one, respectively. The vertical axis is amplitude data read out from an ADC channel. The horizontal axis is a clock number.

INSTALLATION

In September 2014, we installed the WFM-DAQ system into the injection part of the SACLA configured by five LLRF VME systems. The construction of the Cassandra cluster is six nodes and a replication factor of three. We are currently developing the operation GUI. We will start waveform DAQ in November 2014 and finally will take waveform data from 74 LLRF VME systems in 2015.

SUMMARY

We developed a DAQ system for abnormal RF waveforms. The system captures an abnormal RF waveform that suddenly occurs, and stores the waveform data in Cassandra. A prototype system was checked at the test stand. The prototype system worked successfully. We started to install the system into the injection part of LLRF control system in September 2014. The collected data will help to improve the stability of the accelerators.

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