CURRENT STATUS AND UPGRADE PLAN OF THE DATA-ACQUISITION SYSTEM AT SACLA

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Abstract

User experiments at the SPring-8 angstrom compact free electron laser (SACLA) facility were recently commenced, in March 2012. We have developed a dedicated data-acquisition system that can be used for user experiments. This system is currently capable of acquiring data from 10 multiport charge-coupled device sensors at a data rate of up to 5 gigabits per second (Gb/s). In this paper, we present an overview of this data-acquisition system.

OVERVIEW OF SACLA

The SPring-8 angstrom compact free electron laser (SACLA) facility is an X-ray free electron laser (XFEL) facility located at the SPring-8 site in Japan. This facility is characterized by its compact design; it is about 700-m long and includes the accelerator, undulator, and experimental buildings. To achieve the compact XFEL design, we performed the relevant technical development activities such as of the C-band accelerating cavity, in-vacuum undulator, timing, optics, detectors, and data-acquisition system. A significant advantage of the SACLA–SPring-8 experimental facility is that we can use two X-rays, one from SACLA and one from SPring-8, simultaneously. The first self-amplified spontaneous emission (SASE) lasing of SACLA was achieved in June 2011, and X-ray laser beams have been delivered to users since March 2012 [1]. XFEL wavelengths in the subangstrom region (0.6 Å) have been realized. During the first experimental period from March to July 2012, 25 experiments covering atomic, molecular, and optical physics, ultrafast science, material science, and structural biology were carried out.

OVERVIEW OF THE DATA-ACQUISITION SYSTEM

We have developed a dedicated data-acquisition (DAQ) system that can be used for user experiments at SACLA. The DAQ system consists of a number of components: detectors, a front-end system, data-handling servers, a cache storage system, an event-synchronized database (DB), a high-performance PC cluster (HPC), and a large-bandwidth network. We chose standard interfaces to connect components with each other. To match the needs of future experiments, the DAQ performance will be upgraded by replacing the DAQ system components. Figure 1 shows an overview of the SACLA DAQ system. In this section, we describe the current status of each component.

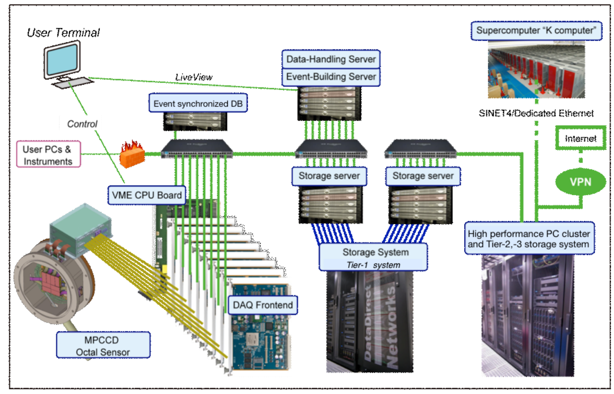

Figure 1: Overview of the DAQ system. The current DAQ system supports up to 10 multiport charge-coupled device sensors.

Multi-Port Charge-Coupled Device Sensors

The multi-port charge-coupled device (MPCCD) sensor is a two-dimensional X-ray detector developed for SACLA experiments [2]. Each pixel of the MPCCD is $50 \times 50\ \mu\text{m}^2$ with a 16-bit data depth. A single MPCCD sensor module has 512×1024 net pixels. Inclusive of calibration data, 512×1032 gross pixels per shot are acquired by the sensor at a repetition rate of 60 Hz. MPCCD sensors can be used in one of the following typical configurations: 1 (single), 2 (dual), and 8 (octal) sensors. We decided to use either the single configuration or the octal + dual combined configuration. For the single and combined configurations (1 and 8 + 2 sensors), data rates are about 500 megabits per second (Mb/s) and 5 gigabits per second (Gb/s), respectively. We have developed downstream components for the DAQ system to satisfy such high data rate requirements.

We chose Camera Link [3] as the digital interface between the MPCCD sensors and the front-end system. By standardizing the front-end interface as the Camera Link, not only MPCCD sensors but other commercial cameras such as IMPERX [4] and OPAL [5] can also be used. The Camera Link interface provides a bandwidth $>$ 2 Gb/s (base configuration), which satisfies the data-rate requirements of the MPCCD sensors.

Front-End System

Because the physical range of Camera Link is short (several meters), the front-end system is aimed at receiving and transferring data from Camera Link to Ethernet. We developed two different front-end systems [6]: a PC-based

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system and a VME-based system. The PC-based system is a one-rack-unit Linux PC equipped with a commercial Camera Link grabber board. The advantage of using the PC-based system is its flexibility in supporting more than 100 commercial cameras, including Camera Link full configuration cameras. The VME-based system has a dedicated field programmable gate array (FPGA) processor to forward image data from Camera Link to Gigabit Ethernet (GbE). The advantage of the VME-based system is its efficient hardware processing. We implemented on-the-fly lossless image compression using the FPGA processor. The I/O interfaces are implemented with a processor PCI mezzanine card and will be upgraded in the future. For practical application, we chose a better system for each detector; PC-based and VME-based systems are used for the OPAL-2000 camera and MPCCD detector arrays, respectively.

Data-Handling Server

Data-handling servers are inserted between the front-end system and the storage system. Each data-handling server corresponds to an individual sensor. The data-handling servers aim at in-line buffering and processing. We implemented a pipeline fast-in-fast-out buffer system on the data-handling server. The pipeline system keeps the DAQ system stable against network packet loss.

We also implemented an on-the-fly low-level filtering system on the data-handling server. The first implemented low-level filtering is a grid-based region-of-interest (ROI) statistical analysis. Figure 2 shows a graphical user interface (GUI) image of the filtering system. The region to the left shows MPCCD image data, and a histogram of the ROI average photon number is shown in the lower right corner. In the current filtering system, each grid is defined as a 4×8 region. The average photon number of each grid is calculated by the data-handling server, shot by shot. The average photon numbers of the grids are recorded on an event-synchronized DB. By choosing a region of interest with the GUI, primitive image-pattern selection can be performed without the need to read the entire image from the storage system.

Storage System

Experimental data are accumulated in three types of tiered storage systems, whose specifications are detailed in Table 1. Tier-1 systems aim at first-level data caching. We suppose that the capacity requirement for the Tier-1 system is about 200–300 terabytes (TB) per week, which is estimated from the data rate of the MPCCD sensors (10 sensors), each with a 50% duty factor. Storage capacities of Tier-1A and Tier-1B systems are 200 and 250 TB, respectively. We intend to use the two systems in rotation; for example, while one system is used for data readout to the Tier-2 system, the other system is used for data acquisition without performance degradation. We chose single-namespace file system (StorNext and GPFS) for the Tier-1 systems, because the numbers of sensors can vary in every experiment. The minimum guaranteed throughput of the Tier-1 system is 70 megabytes per second (MB/s) with 10 simultaneous streams, which satisfies the required data rate of the MPCCD sensors (60 MB/s, $8 + 2$ sensors). It should also be noted that the average throughput of the Tier-1 system is 500 MB/s, which satisfies the estimated data rate of the silicon-on-insulator photon imaging array sensor (SOPHIAS), which is under development.

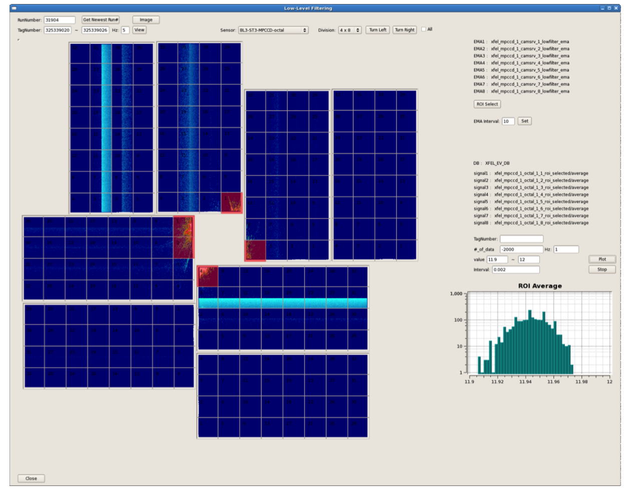

Figure 2: GUI image of the low-level filtering system. The region to the left shows MPCCD image data. A histogram of the ROI average photon number is shown in the lower right corner.

Tier-2 and Tier-3 storage systems will be installed in March 2013. Tiers 2 and 3 aim at long-term data archiving (over more than one year). The Tier-2 system consists of a 1 petabyte (PB) disk array having more than 2 gigabytes per second (GB/s) throughput. The Tier-3 system is an automated tape-library system equipped with 12 tape drives (IBM TS1140) and 7500 tape-cartridge slots (IBM 3592 specifications). The initial capacity of the tape library is 6 PB with 1700 cartridges. The average throughput of a single drive is 200 MB/s. By using GPFS and hierarchical storage management software (TSM), Tier-2 and Tier-3 are united into a single-namespace file system.

Event-Synchronized Database

The XFEL is a discrete beam operating at a 60 Hz repetition rate. To distinguish event data corresponding to each X-ray shot, we developed an event tag system and an event-synchronized DB system [7]. The timing signal is distributed from the XFEL master trigger at 60 Hz. The front-end system utilizes the timing signal both for acquiring the trigger and for shot-number counting. Acquired data from beam-line monitors are tagged by the shot number and are recorded on the event-synchronized DB. An experimental user can acquire beam monitor data from the event-synchronized DB by specifying a certain tag number or timestamp.

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Table 1: Specifications of the storage systems. Tier-1 systems are used for first-level data caching. Tiers 2 and 3 are used for long-term data archiving.

Tier	Capacity	Throughput	Hardware	Media	File System
1A	200 TB	70 MB/s (min.) $\times$10 streams 500 MB/s (avg.) $\times$10 streams	DDN S2A9900	HDD (SAS)	Quantum StorNext
1B	250 TB	70 MB/s (min.) $\times$10 streams 500 MB/s (avg.) $\times$10 streams	DDN SFA10000	HDD (SAS)	IBM GPFS
2	1 PB	>2 GB/s	DDN SFA10000	HDD (SATA)	IBM GPFS
3	6 PB	200 MB/s (avg.) $\times$12 drives	IBM TS3500	Tape (3592)	IBM GPFS and TSM

High-Performance PC Cluster

Because the obtained images from X-ray diffraction experiments are reciprocal lattice spaces, a sophisticated calculation is necessary to extract real-space images. For these analyses, an HPC system has been installed in the SACLA computer room. Performance of the HPC system is 13 TFLOPS with 170 TB of shared storage system. The HPC system is used not only for off-line analysis but also for on-line instant visualization. Real-space images from on-line reduced analyses help to determine the feasibility of carrying out the experiment. By examining these images, we can determine whether the experimental conditions need to be changed.

Large-Bandwidth Network

The SACLA experimental network consists of three local-area networks (LANs) [8]: DAQ-LAN, DAQ-USER-LAN, and HPC-LAN. In this paper, overviews of DAQ-LAN and HPC-LAN are presented.

The DAQ-LAN is a dedicated network for the data-acquisition system. The DAQ-LAN has two physical network layers: a 10-GbE layer for data transfer and a 1-GbE layer for instrumental control from the user terminal. We segregate the two physical backbones to ensure a high bandwidth of data transfer. We apply link aggregation for the purpose of redundancy. The DAQ-LANs (10 GbE and 1 GbE) are available at every experimental hutch and every experimental station.

We also have another dedicated LAN for data analysis: the HPC-LAN. The HPC-LAN is a backbone network for data exchange among Tier-1, -2, and -3 storage systems and the HPC system. The HPC-LAN is also connected to a 10-Gb wide-area network for the purpose of cooperative analysis using external supercomputers.

UPGRADE PLAN FOR THE DATA-ACQUISITION SYSTEM

We are developing a next-generation X-ray sensor, referred to as SOPHIAS [9]. This sensor is being developed to achieve a higher dynamic range than the present MPCCD sensors. A single SOPHIAS module has 1024×2048 net pixels with a 32-bit data depth. The SOPHIAS detector will have maximum sensor number of 40. The maximum total data rate is about 20 GB/s at a 60-Hz XFEL repetition rate. Operation of the first SOPHIAS detector with a two-sensor configuration will begin in 2014. To satisfy the data rate of SOPHIAS (480 MB/s for a single sensor), we started developing a new front-end system [10]. According to our plan, the new front-end system supports data rates of up to 2.5 GB/s for the future 300-Hz repetition rate. We are also examining the requirements of the data-handling servers and DAQ-LAN.

We also plan to perform sophisticated on-line analysis using external supercomputers. For the coherent X-ray diffraction imaging experiment [11], our HPC system is insufficient for performing on-line instant visualization. By utilizing external peta-FLOPS class supercomputers, such as the "K computer" [12], we will be able to refine experimental conditions quickly during an ongoing experiment.

SUMMARY

User experiments with SACLA were recently commenced, in March 2012. A dedicated DAQ system has been developed for the user experiments, and this system is now fully operational. We started developing new DAQ components to support the next-generation X-ray sensor SOPHIAS. In 2014, the new sensor and the upgraded DAQ system will come into operation. We have also started developing a cooperative analysis procedure using external supercomputers.

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