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STATUS OF THE CONTROL SYSTEM FOR FULLY INTEGRATED SACLA/SPring-8 ACCELERATOR COMPLEX AND NEW 3 GeV LIGHT SOURCE BEING CONSTRUCTED AT TOHOKU, JAPAN

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Abstract

In the SPring-8 upgrade project, we plan to use the linear accelerator of SACLA as a full-energy injector to the storage ring. For the purpose of simultaneous operation of XFEL lasing and on-demand injection, we developed a new control framework that inherits the concepts of MADOCA. We plan to use the same control framework for a 3-GeV light source under construction at Tohoku, Japan. Messaging of the new control system is based on the MQTT protocol, which enables slow control and data acquisition with sub-second response time. The data acquisition framework, named MDAQ, covers both periodic polling and event-synchronizing data. To ensure scalability, we applied a key-value storage scheme, Apache Cassandra, to the logging database of the MDAQ. We also developed a new parameter database scheme, that handles operational parameter sets for XFEL lasing and on-demand top-up injection. These parameter sets are combined into 60 Hz operation patterns. For the top-up injection, we can select the operational pattern every second on an on-demand basis. In this paper, we report an overview of the new control system and the preliminary results of the integrated operation of SACLA and SPring-8.

SPring-8 UPGRADE AND 3 GeV LIGHT SOURCE PROJECTS

Synchrotron radiation (SR) is necessary in many scientific fields such as material science, biological science, non-linear optics. More than two decades have passed since the third-generation SR facilities established, such as APS, ESRF, and SPring-8. To maintain the top performance, we have begun upgrading the SPring-8 [1]. The upgrade plan aimed to improve the brilliance by 100 times with 1/20 beam emittance than the present facility. To achive the requirement, we use SACLA [2], which is an X-ray free electron laser (XFEL) facility, as a injector. In order to achieve such a combind operation of two facilities, we have to upgrade present control framework.

Another SR facility project is underway in Japan. A compact 3 GeV light source project [3] has been approved by the Japanese Government from fisical year 2019. The accelerator components are designed based on previous studies of the SPring-8 upgrade project. Under such a circumstance, we proposed the new framework developed for the SPring-8 upgrade project.

In this paper, we show the basic concepts of the control framework MADOCA, presently used at the SPring-8 accelerator complex. We also show the design overview of the new control framework, which is took over the concepts of MADOCA. The current status of the new control framework development and application not only to the SPring-8 acclerator complex but also the 3 GeV light source are shown.

MADOCA CONTROL SYSTEM AND ITS LIMITATIONS

MADOCA (Messaging and Database orianted control architecture) is a control framework developed for the SPring-8 storage ring control [4]. MACOCA is characterized as S/V/O/C style messaging, whose idea was derived from English grammar. Computer networks are used as field buses for messaging between workstation and device contorllers. By using standard TCP/IP-based communication, we can use commercial off-the-shelf network instruments, such as Ethernet. Another key component of the MADOCA is the database system. We use SYBASE, which is a relational database system, as the central database system. The SYBASE is used for both instrument logging and save/recall operation parameters.

The original MADOCA was developed to control the SPring-8 storage ring in 1997. Subsequently, the MADOCA was also applied to the SPring-8 injector accelerators. [5] The MADOCA is also applied to other accelators outside of the SPring-8 campus, for example, the HiSOR at Hiroshima University [6] and SCRIT at RIKEN RI beam factory. In 2011, the X-ray free electron laser facility SACLA commenced operation. For the control system of the SACLA, we applied the MADOCA. The beam operation of SACLA is different from SPring-8. SPring-8 is a storage ring; therefore, beam operation is based on periodic polling basis. On the other hand, SACLA is single-path beam machine with 60 Hz repetition rate; therefore, beam operation is on an event-synchronized basis. To complement the limitations of MADOCA, we have developed many control subsystems, such as event-synchronized data acquisition (DAQ) system [7], abnormal waveform recorder [8], and more. To operate two acclerator facilities SACLA and SPring-8 storage ring as one machine, we must integrate all the control sub-systems. Considering these circumstance, we started upgrading the MADOCA control framework [9].

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CONCEPT AND DEVELOPMENT STATUS OF THE NEW CONTROL FRAMEWORK

Messaging

In the legacy MADOCA framework, the message server (MS) uses remote procedure call (RPC) for communication between the operator workstation and device controllers. Since the RPC is a primitive protocol, the coding procedure is complicated. To resolve the complexity of messaging, we adopt the open-standard MQTT [10] as the messaging protocol for the new control framework. The MQTT is characterized by pub/sub model, light-weight, and centralized message broker. Particularly, debugging is an advantage of the MQTT, because all messages are logged in the central message broker. We tested the feasibility of the MQTT-based messaging system with the RF teststand [11].

We choose eMQTT [12] as MQTT broker software. Since the MQTT broker is a key component of the messaging system, high availability (HA) should be considerd. In the case of SPring-8/SACLA, hundreds of users perform experiments simultaneously during the machine time. For such an accelerator case, we use active-active HA computer like Stratus ftServer. For the other case, such as test accelerator, we use active and cold-standby computer.

Database Systems

The database is one of most important components of the MADOCA control framework. The database systems are used for three purposes; online logging, data archiving, and parameter management. In the legacy MADOCA framework, we have used SYBASE as the database system for these purposes. Since SYBASE is proprietary software, it was difficult to scale up the database performance owing to budget constraints. Therefore, we decided to use open-source software as the database system in the new control framework [13].

Figure 1 shows the schematic view of the database system. We use Cassandra [14] for the online logging database. The characteristic features of Cassandra are key-value storage, performance scalability, high-availability without single point of failure, and cross-language compatilibity using Thrift [15] framework. Since the Cassandra has high-availability on its own, we can choose low-cost computers for Cassandra nodes. We also use MariaDB for data archiving and parameter management, because mid-term scalability is not currently required. For the purpose of the parameter database, we use fault-tolerant server computer to ensure high availability. High availability is not necessary for the purpose of the archive database, we use PC server.

DAQ Framework

Table 1 shows the legacy DAQ systems in SPring-8/SACLA. The DAQ system of the MADOCA native framework uses only polling basis [16]. To complement DAQ functions, we developed DAQ sub-systems for each purpose. These sub-systems are controlled by the MADOCA Equipment Manager Agent (EMA) framework. To integrate the DAQ systems into one framework, we developed a new DAQ framework, which is named "MDAQ".

MDAQ is designed as a unified extention of the EMA-based DAQ systems. Figure 2 shows the software design of MDAQ. One device controller has only one Equipment Manager (EM) process. Multiple MDAQ processes are permitted, and the MDAQ processes are forked by the EM. The user functions of MDAQ are identical to the EM, except for the initialize and finalize sequence. During initialization of MDAQ process, MDAQ gets the DAQ parameter from the parameter database, such as DAQ Type (polling / synchronized), polling period, and accelerator type (SPring-8 / SACLA). The MDAQ process create `event_watcher`, `daq_func`, and `data_filler` threads according to the DAQ parameters. With the flexibility of the `event_watcher`, we can integrate polling-based and trigger-based DAQ into one framework. For the polling DAQ (POL), acquisition period is counted by the `event_watcher` thread internally. For synchronized DAQ (SYNC), acquisition timing is determined by an external trigger. Every acquisition period, `event_watcher` thread sends a signal to the corresponding `daq_func` thread. If the `daq_func` thread receieved the signal, the `daq_func` thread reads value from instruments and the data are queueing. The `data_filler` thread asynchronously read data from queue, then sends CQL-converted data to the online database. MDAQ POL can support 0.1 sec. period , because `daq_func` and `data_filler` threads are asynchronous, and each thread can concentrate on the tasks.

Table 2 shows the planned DAQ types. POL, SYNC, and Waveform are already supported by the MDAQ. The image DAQ system is under development, and we plan to run the prototype system from early 2020.

SYSTEM MIGRATION TO THE NEW CONTROL FRAMEWORK.

Migration Steps

The new control framework project started in 2015. Development and field test are performed at not only testbench system, but also two small accelerators in the SPring-8 campus; one is dedicated accelerator for soft X-ray FEL [17] and another is NewSUBARU 1.5 GeV SR ring [18].

In May 2017, we performed field tests using dedicated accelerator. During the test, we picked up typical device controllers from magnet control, vacuum control, and RF control. Each device controller wes run by the new control system for a week. From the test results, we concluded that the new control framework is ready to migrate.

The migrations to the new control system are performed step by step at the SPring-8 accelerator complex. At first, we migrated all control system of the dedicated accelerator during the summer shutdown period in 2017. By succeeding of the migraion of the dedicated accelerator, we next started migrating SPring-8 control system. In the case of SPring-8, we planned partially migrate control systems, because number of device controllers are too large. We decided to migrate SPring-8 storage ring control system only. But in-

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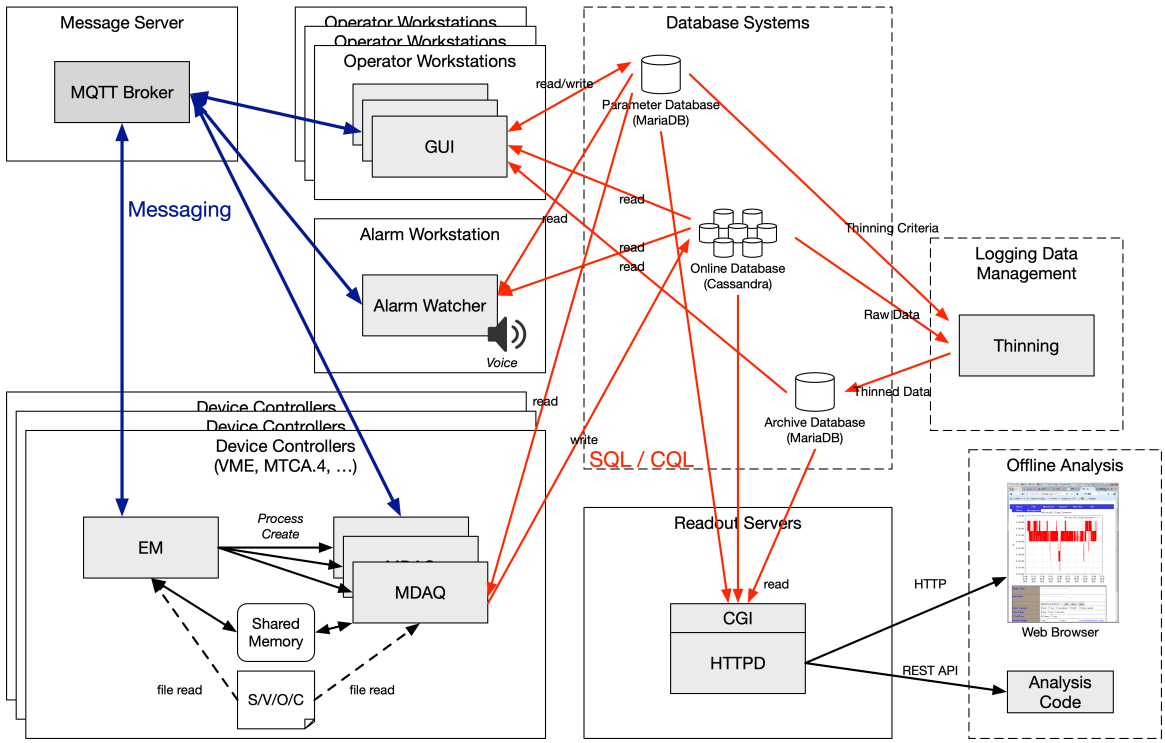

Figure 1: Schematic View of the new control framework. The framework is characterized by messaging (blue arrow) and database access (red arrow).

Table 1: Legacy DAQ systems running at the SPring-8 and the SACLA. Due to historical circumstances, data stores are different by each data type. EMA is an additional framework to the MADOCA to support event-driven basis.

DAQ Type	Data Type	Timing	Data Store	MADOCA Framework
POL	point	1–10^2 sec. period	SYBASE	Native Supported
SYNC	point	Triggered (typ. 60 Hz)	MySQL	EMA Supported
Waveform	array	Triggered	Casandra	EMA Supported
Image	image	Triggered (typ. 60 Hz)	NFS	EMA Supported

Table 2: DAQ types supported (and under developping) in the new control frawmework.

DAQ Type	Data Type	Timing	Data Store	New DAQ Framework
POL	point	0.1–10^2 sec. period	Cassandra	Native Supported
SYNC	point	Triggered (typ. 60 Hz)	Cassandra	Native Supported
Waveform	array	Triggered (typ. up to 100 shots at 10 Hz rate)	NFS	Native Supported
Image	image	Triggered (typ. 60 Hz)	NFS	(under developping)

jector control systems are remained as MADOCA, because present injectors will be shutdown after completing SACLA injection. The beamline control systems will also remains MADOCA for a few years. To communicate between the legacy MADOCA and the new control system, we also developed messaging gateway software. During the spring shutdown in 2018, the control system of SPring-8 storage ring migrated to the new control system. The control system of SACLA migrated during the summer shutdown in 2018. Table 3 shows number of device controlls in the control systems in SPring-8 accelerator complex. Note that "Not Migrated" includes under developing hosts (image DAQ), and obsolete hosts.

On-demand Beam Injection

We plan to use SACLA linac as full-energy injector of SPring-8 storage ring. To inject electron beam into SPring-8 storage ring, we must tune electron beam parameters such as energy and bunch length. During the machine time of XFEL, electron beam energy is tuned to required XFEL lasing parameter. Bunch length is less than 10 fs for the lasing condition. On the other hand, injected electron beam energy must be tuned to the parameter of storage ring completely. A

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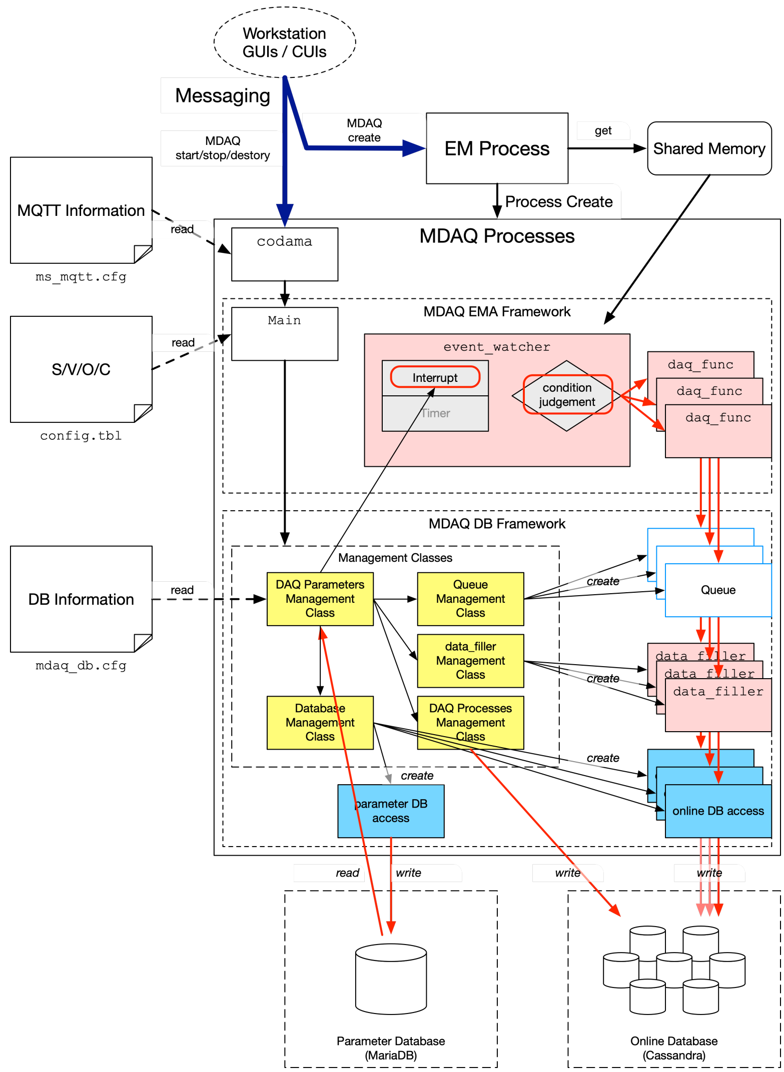

Figure 2: Software architecture of the MDAQ.

Table 3: Number of device controllers running in the SPring-8 accelerator complex. "Not Migrated" hosts are under developing (image DAQ) or obsolete hosts.

Accelerator	Devices	Migrated	Not Migrated
SPring-8 Storage Ring	182	171	11
SACLA	200	193	7
SCSS+	54	51	3

long bunch length is prefered to reduce coherent synchrotron radition effect in the transport line. Therefore electron beam parameter must be tuned, when we inject electron beam into SPring-8 storage ring.

With the SPring-8 top-up operation, beam injection is required every tens seconds period. Operation ratio of SPring-8 injection to XFEL lasing is about 1/1000. To maximize beam operation, we developed on-demand beam route and RF parameter switching system [19]. In this scheme, we tune electron beam parameter by changing RF parameters shot-by-shot. Beam route and RF parameters are distributed among RF systems. To ensure real-time distribution, we use reflective memory network in addition to the Ethernet. Distributed beam route and RF parameters are also recorded using MDAC SYNC, to verify delivered beam parameters.

PRESENT STATUS AND OUTLOOK OF 3 GeV LIGHT SOURCE AT TOHOKU

The 3 GeV SR facility project is in progress. From early 2019, land creation has started at the Aobayama campus of Tohoku University. First light of the new facility is scheduled in 2022. To meet the such short schedule, the new facility use technologies studied for SPring-8 upgrade project. We,

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control group of SPring-8/SACLA, propose the new control framework to be used at the new SR facility.

Studies of prototype linac for the 3 GeV SR facility started at SPring-8 site. The prototype linac will be installed at the transport line of present NewSUBARU facility in 2020. Using the prototype linac and NewSUBARU storage ring, we will test accelerator components including control system prior to construction of the 3 GeV SR facility.

SUMMARY

We developed a new control framework to keep up with requirements from SPring-8/SACLA accelerator operations. The new control framework takes over phillosophy of the present MADOCA control framework. We developped and deployed the new control framework to the accelerator complex in the SPring-8 site. The new control system is ready to perform electron beam injection from the SACLA linac to the SPring-8 storage ring. We also plan to deploy the control system into new 3 GeV SR facility at Tohoku, Japan.

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