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DEVELOPMENT OF NEW MADOCA CONTROL SYSTEM FOR SPring-8-II

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Abstract

The MADOCA control system was developed for the SPring-8 in 1997. In 2025, the SPring-8 upgrade project, "SPring-8-II", will start. Toward the SPring-8-II, we decided to renovate the MADOCA control system. The new control system, named "MADOCA 4.0", inherits the concepts of the former MADOCA, which are characterized by SVOC-style messaging, a database-oriented framework, and a distributed control design using a network system. In contrast to the inherited concepts, we are renewing the base technologies. For edge computing, we use both MicroTCA.4 and generic PC servers instead of the outdated VME system. By combining EtherCAT with these edge computers, we support various I/O interfaces with simple wiring. We also provide a REST API as a database reading method to support external system linkage.

INTRODUCTION

SPring-8 is the largest synchrotron radiation facility in the world. Nearly three decades have passed since user operation started in 1997. To improve the competitiveness of the facility, it is necessary to upgrade the SPring-8. The SPring-8-II upgrade project is approved in fiscal year 2025 [1]. The present SPring-8 will be shut down in 2027, and we will start upgrading the facility. Then the SPring-8-II will resume operation in fiscal year 2028.

We use MADOCA, a control framework to operate the SPring-8 and the X-ray Free-electron laser facility SACLA [2, 3]. Because the MADOCA is based on 1990s computing technologies, it is also necessary to upgrade the control framework. We started upgrading MADOCA prior to the SPring-8-II upgrade project [4, 5].

We named the new control framework "MADOCA 4.0". We are renewing base technologies of MADOCA 4.0, whereas MADOCA 4.0 inherits the original MADOCA concepts. In this paper, we present an overview of MADOCA 4.0 and report the progress of its implementation.

MADOCA CONTROL SYSTEM

The MADOCA control framework is characterized by SVOC-style messaging, a database orientation, and a distributed control system connected to a network. In 1997, the SPring-8 control system consisted of PA-RISC HP-UX workstations, a SYBASE database engine, VME edge computers, and an FDDI/Ethernet network. By utilizing the MADOCA framework, we integrated these components into a unified control system.

We have made minor changes, such as switching to x86 Linux instead of HP-UX, operating system (OS) upgrades, and replacing the network with wide-bandwidth Ethernet. While MADOCA kept its basic technologies for two decades, information technology made significant progress, for example, in 64-bit processors, various implementations of database engines, and sophisticated messaging protocols. We decided to upgrade the MADOCA control framework, incorporating modern technologies.

Figure 1 shows an overview of the MADOCA 4.0 control framework. We set a target for the MADOCA 4.0 as part of the Fourth Industrial Revolution (Industry 4.0). To realize this feature, we upgraded MADOCA as follows:

1. Sophisticated messaging
2. Data acquisition upgrades
3. Database improvement to support the DAQ framework

These three components were installed in the present facilities prior to the SPring-8-II: SCSS+, a dedicated accelerator for the soft X-ray laser for SACLA BL1 in 2017; SPring-8 storage ring in 2018; and SACLA in 2019. By integrating these facilities with a unified control framework, we can use the SACLA linac as a full-energy injector to the SPring-8 storage ring in 2020.

We are continuing further development as follows:

4. Device controller upgrades
5. Operator workstation renewal
6. API implementation to support external systems

MADOCA 4.0 is partly installed at NewSUBARU in 2021 [6] and NanoTerasu in 2024 [7]. Both NewSUBARU and NanoTerasu successfully started user operation.

MESSAGING

Modern accelerators that utilize computer systems need messaging functions between the central control and the field components. MADOCA is characterized by a messaging function that uses SVOC-style syntax similar to English. The original MADOCA used an in-house developed remote procedure call (RPC) as the communication protocol. To develop MADOCA 4.0, we replaced the communication protocol with Message Queueing Telemetry Transport (MQTT). MQTT is a lightweight messaging protocol, and its features include a pub/sub model and reliable reachability. By maintaining the SVOC-style syntax, compatibility with higher-layer software is also maintained.

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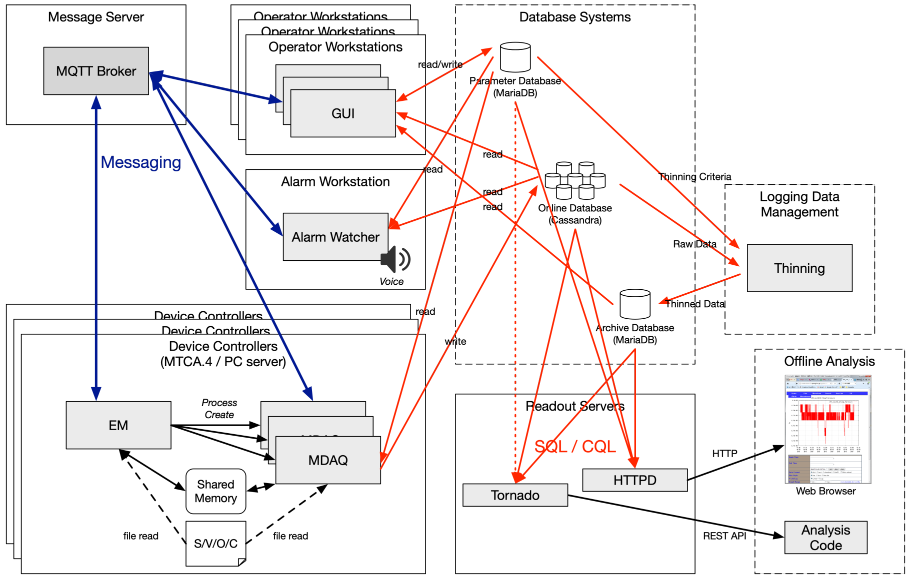

Figure 1: Overview of MADOCA 4.0 control framework.

Multithreading is an important technology for utilizing the capabilities of multi-core CPUs and improving software performance. The original MADOCA was not thread-safe. One of the reasons is that there is no mechanism to ensure the integrity of sent and received messages. MADOCA 4.0 implements several improvements, such as assigning IDs to messages and improving buffer handling. The framework has been rewritten to be thread-safe and now runs multi-threaded by default. MDAQ, which is described later, also benefits from multi-threading.

DATA ACQUISITION

Data acquisition (DAQ) is one of the core features of the MADOCA control framework. In the original MADOCA framework, DAQ was implemented as asynchronous polling, which was appropriate for the storage ring control. On the other hand, SACLA is a pulse accelerator with a 60 Hz repetition rate. To adopt pulse-based accelerator control, we developed an event-synchronized DAQ system [8]. However, polling and event-synchronized DAQ frameworks remained separately implemented. In order to use the SACLA linac as a full-energy injector for the SPring-8 storage ring, it was necessary to integrate the DAQ frameworks. To achieve these requirements, we implemented a new DAQ framework for MADOCA 4.0.

The new DAQ framework, named “MDAQ”, is implemented on an event-driven basis. Polling is implemented as a periodic timer-driven method. Using the event-driven basis, we can also implement one-shot DAQ, which is useful for beam injection monitoring and abnormal event monitoring. We also implemented DAQ of waveforms and images for MADOCA 4.0, whereas the original MADOCA supported point data only. In the case of waveforms and images, the actual data are stored on a file server, and the file pointers are stored in the database. MDAQ provides all these DAQs within one framework.

DATABASE

MADOCA is a unique control framework that makes use of a database system since its development [9]. The database system is used for following purposes:

1. Logging database
2. Parameter database

Logging Database

The logging database is intended to record the status of accelerator components. We provide two logging database systems. The first is the online database, and the second is the archive database. The online database logs polling, event-synchronized, and one-shot data. To match the DAQ performance requirements, we selected a NoSQL engine for the online database. NoSQL engines can scale out and meet future performance demands. Table 1 shows configuration of the online databases. We selected Cassandra as the NoSQL database engine.

The guaranteed retention period of the online data is three months. Before this period ends, we thin out online data and record it in the archive database. The archive database is intended to record thinned-out data for the long term. We selected a relational database (RDB) engine to maintain data consistency. Table 2 shows configuration of the archive databases. Because of backward compatibility with legacy Solaris OS, we selected MariaDB 10.3 for the RDB engine.

Parameter Database

Parameter database is another characteristic feature of the MADOCA framework. By recording operating parameters

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Table 1: Online Database Systems

Accelerator	NoSQL Engine	Number of Nodes	Performance Required Polling	Performance Required Synchronized
SPring-8	Cassandra 3.11	60	15 kHz	2.7 kHz
SACLA	Cassandra 3.11	72	18.6 kHz	200 kHz
SCSS+	Cassandra 3.11	30	2.6 kHz	16.8 kHz

Table 2: Archive Database Systems

Accelerator	RDB Engine	Number of Nodes
SPring-8	MariaDB 10.3	2 (main/replica)
SACLA	MariaDB 10.3	2 (main/replica)
SCSS+	MariaDB 10.3	2 (main/replica)

in the database, we can easily resume accelerator conditions. The parameter database gives advantages to SPring-8/SACLA as a user facility.

Table 3 shows configuration of the parameter databases. Since the SACLA linac is an injector to the SPring-8 storage ring, two accelerators share one parameter database. We use a fault-tolerant (FT) server for SPring-8 and SACLA, because high availability is required for these accelerators.

Table 3: Parameter Database Systems

Accelerator	RDB Engine	Number of Nodes
SPring-8 / SACLA	MariaDB 10.3	1 (FT server)
SCSS+	MariaDB 10.3	2 (main/cold backup)

DEVICE CONTROLLER

Device controllers are distributed edge computers that are directly connected to accelerator components. Software called "Equipment Manager" (EM) runs on the edge computer, allowing accelerator components to be controlled from central operator workstations. The VME platform has been used for a long time since the beginning of SPring-8. Since the VME is becoming end-of-life, it is necessary to select a next-generation computing platform. MicroTCA.4 (MTCA.4) was selected for applications requiring high-speed feedback, such as low-level RF, and beam monitors [10–13]. General-purpose x86 servers (PC servers) were also selected for medium-speed control [14].

We chose Ubuntu Linux as the operating system for MTCA.4 and PC servers. Depending on the installation time, Ubuntu 16.04 LTS is running on both MTCA.4 and PC servers. In the near future, we plan to upgrade to Ubuntu 22.04 LTS.

A key technology of edge computing in MADOCA 4.0 is the introduction of EtherCAT. EtherCAT is an open-standard industrial field network developed by Beckhoff Corporation [15]. By utilizing EtherCAT, it is possible to build a control system by combining devices from multiple manufacturers. The first EtherCAT application at SPring-8 was an insertion device (ID) control system in 2018. By installing an EtherCAT board into existing VME chassis, we replaced the motor driver control system instead of the existing legacy one [16]. Our ID control system has been moving toward PC servers with an EtherCAT configuration. In 2024, we installed the first VME-free ID control system using PC servers and EtherCAT [17].

OPERATOR WORKSTATION

For accelerator operation, the operator workstation is also important as a man-machine interface. At the beginning of the SPring-8, we selected PA-RISC-based HP-UX workstations equipped with X-MATE GUI builder. In 2007, we moved to x86-based SUSE Linux workstations, whereas we continued to use the X-MATE. Due to the heavy license fees for the commercial Linux distribution, we plan to replace the operator workstations.

We selected Ubuntu 22.04 LTS as the OS of new operator workstations, identical to the device controllers. We also selected Qt as the new GUI builder. For backward compatibility, the X-MATE library is also ported to Ubuntu. For SPring-8 control, we finished replacing the operator workstations at the end of 2024 [18]. For the SACLA and SCSS+ control, we plan to replace the operator workstations in 2025.

SUPPORT FOR EXTERNAL SYSTEMS

Machine learning and artificial intelligence are becoming increasingly important in accelerator science. MADOCA 4.0 provides two methods for linking to external systems. The first is a C-language function that is supported by the original MADOCA. For example, a machine-learning-based beam optimizer is already in operation at SACLA [19]. The second is a REST API. At the moment, we provide logging database information via a REST API. We also plan to provide parameter database information in the near future.

CONCLUSIONS

We have been developing the MADOCA 4.0 control framework. Some of the new features have been deployed to the current SPring-8/SACLA/SCSS+ accelerators prior to SPring-8-II. We also deployed the MADOCA 4.0 framework to NewSUBARU and NanoTerasu. We continue to develop unimplemented features of MADOCA 4.0, and then we will ensure the SPring-8-II operation.

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