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The high level application architecture of the control system for SHINE

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ABSTRACT

Shanghai HIgh repetition rate XFEL aNd Extreme light facility(SHINE) is a quasi-continuous wave hard X-ray free electron laser facility, which is currently under construction. Such kind of accelerators typically comprise more than hundreds of devices, and control systems are required to manage all the devices in a uniform manner. The control system of SHINE will be based on Experimental Physics and Industrial Control System (EPICS) with a dedicated high-speed data channel and an integrated information system to fulfill the requirement of high repetition rate. Then the high level control applications are designed to hold the information base as well as a set of cooperating services for data access. Modular design is utilized to simplify development and deployment. Modules of parameter and lattice/model are introduced as examples.

1. Introduction

Owing to the wide range of applications of X-rays in the research fields of physics, chemistry, and biology, facilities with the ability to generate X-rays were developed continuously in the last century. The free electron laser (FEL) is a novel light source, producing high-brightness X-ray pulses. To achieve high-intensity and ultra-fast short wavelength radiation, several X-ray FEL facilities have been completed or under construction around the world [1].

Motivated by the successful operation of X-ray FEL facilities worldwide and the great breakthroughs in atomic, molecular, and optical physics, condensed matter physics, matter in extreme conditions, chemistry and biology, the first hard X-ray FEL light source in China, the so-called Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE), is under construction. SHINE will utilize a photocathode electron gun combined with the superconducting Linac to produce 8 GeV FEL quality electron beams with 1 MHz repetition rate [1].

The automation control system is important for the operation of an accelerator. It is responsible for the facility-wide device control, data acquisition, machine protection, high level database or web applications as well as network and computing platform. Meanwhile it will provide operators, engineers and physicists with a comprehensive and easy-to-use tool to control the machine components to produce high quality electron beam and free electron laser. In the control system, the high level database provides a platform to hold the information base. These data include the static information of control devices, runtime information of control signals as well as physics lattice and commissioning information. The data and related applications can be used to manage design lattices, model them, tune the beams, troubleshoot, manage calibration data, maintenance records, alignment information and quality metrics, and generate reports for regulatory agencies. Details of control system architecture and high level database and applications are described in the following sections.

2. Control system architecture

The high repetition rate and the potentially high data throughput present a great challenge in the control system that will require powerful fast feedback capabilities, large data processing capacities, etc. The control system of SHINE will be mainly based on EPICS to reach the balance between the high performance and costs of maintenance according to the previous experience of Shanghai Synchrotron Radiation Facility (SSRF) and the Shanghai soft X-ray Free-Electron Laser facility(SXFEL). EPICS is a set of open source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as particle accelerators, telescopes and other large scientific experiments [2]. In order to fulfill the requirement of the high repetition rate, a dedicated high-speed data channel will be integrated into the control system. What is more, there is a need for an integrated information system that manages the data generated during the design, construction, commissioning and operation. Therefore, the control system is divided into four layers as illustrated in Fig. 1, which are operator interface layer, middle layer, device control layer and data acquisition layer.

The operator interface layer offers graphical user interface (GUI), command line interface (CLI) and high-level application programming interface (API) to operators, engineers and physicists. The middle layer

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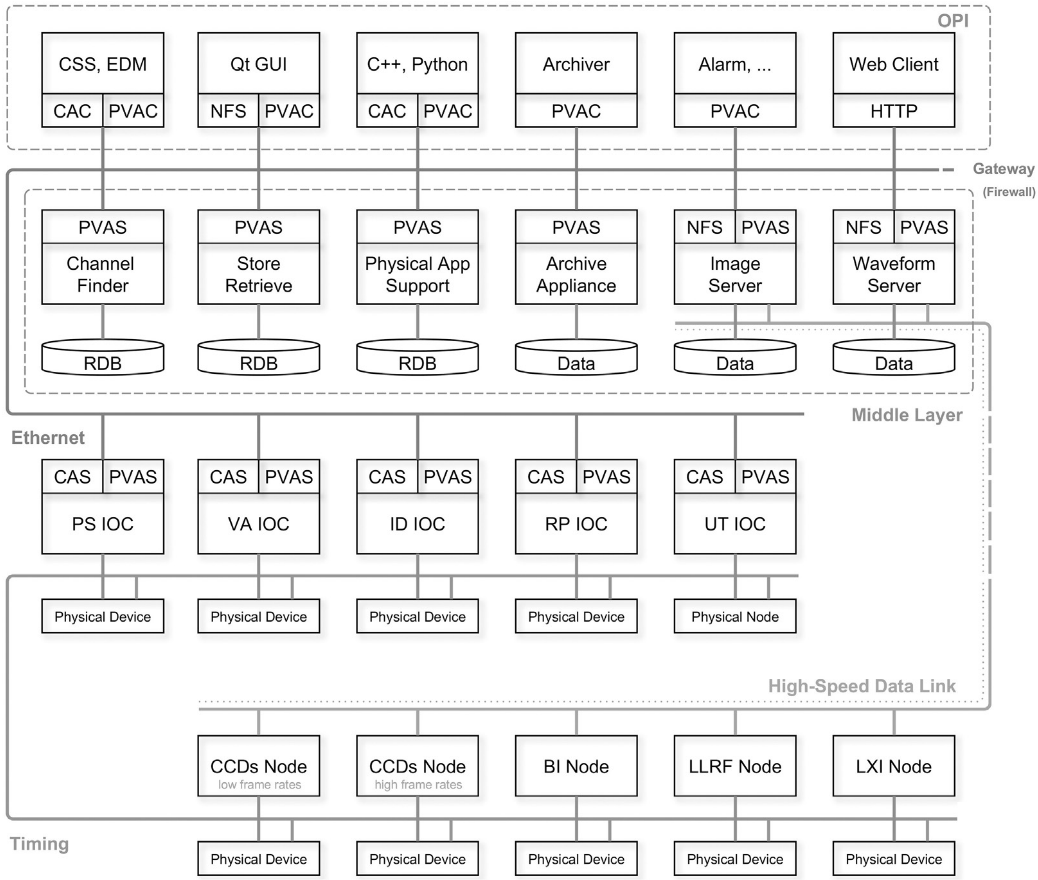

Fig. 1. Architecture of the control system.

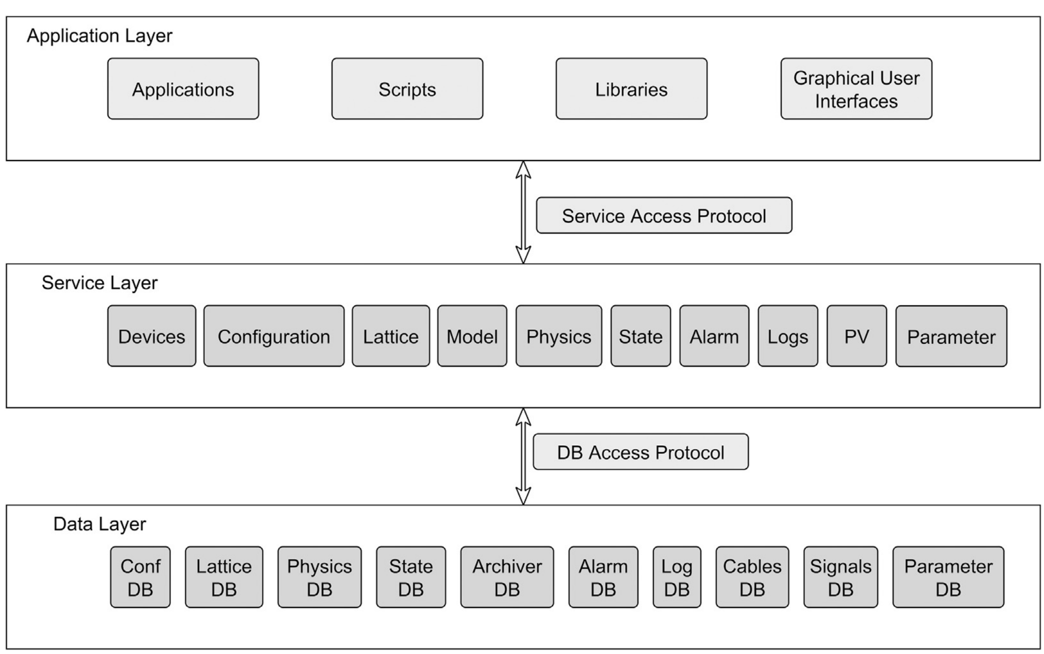

Fig. 2. Architecture of high level application.

consists of computation, storage and network devices. It provides the runtime environment for the whole control system. It also completes the centralized processing tasks for image and stream data acquisition system. The device control layer is responsible for the facility-wide input and output device control. The data acquisition layer is designed for the high speed image and stream data acquisition, processing and storage.

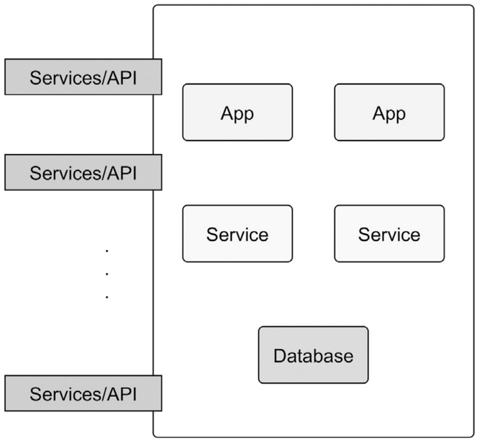

Fig. 3. Module architecture.

3. The high level application

Residing between the low-level device control and high-level operator interface, the database-driven middle layer plays an important role in the whole control system for SHINE. It is normally referred to as the high level application. It combines relational data, aggregated data and computed data throughout the entire life cycle of an accelerator [3]. The high level application provides a platform to hold the information base, as well as a set of cooperating services for data access. The detailed architecture of the high level application is shown in Fig. 2.

It is composed of three parts: database, service, and application. The database is a general data storage container for all the data such as machine configuration, lattice, model, physics, machine state, archiver, alarm, cables, design parameters, as well as runtime data from EPICS. The relational databases will be widely used combined with non-relational databases for stream data. The service implements a series of control and physical related logic operations, and provides standard interfaces for the application layer, including local interfaces and remote interfaces. The application layer consists of many kinds of tools and

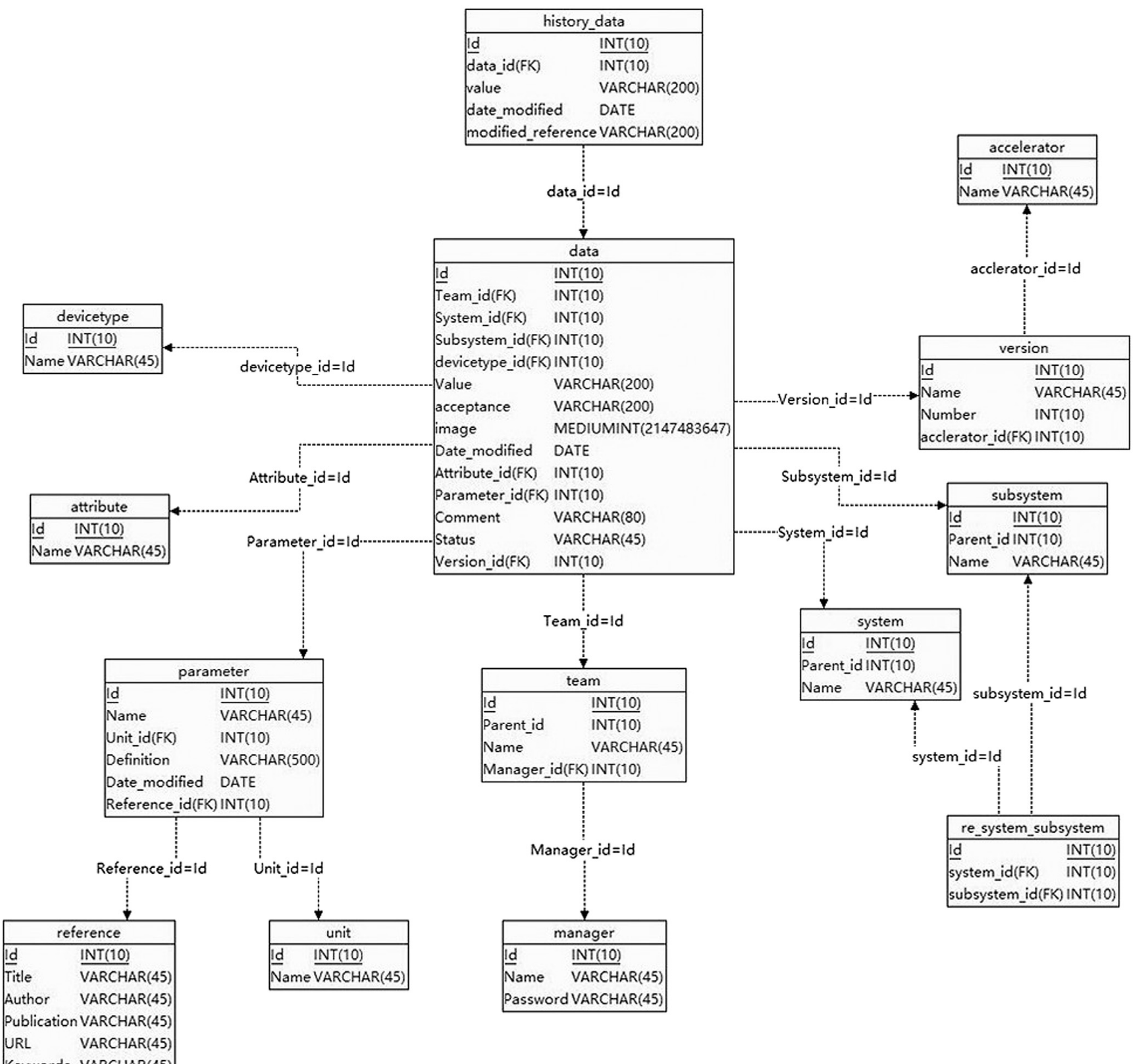

Fig. 4. Parameter database schema.

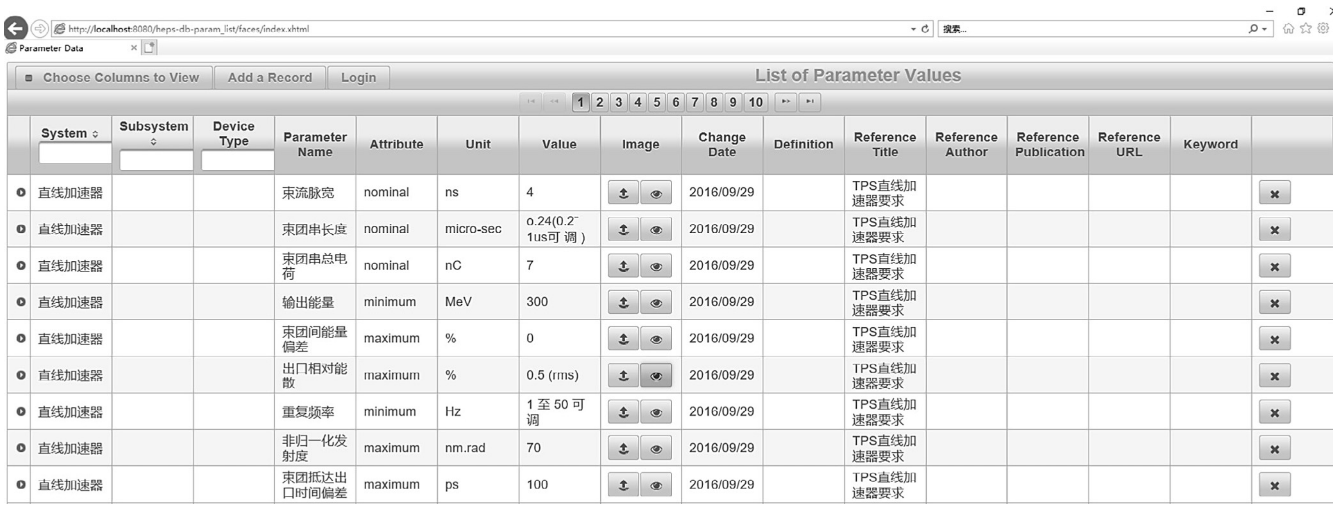

Fig. 5. Design Parameter Database Web UI.

components used to display the information to users. Both web-based and desktop-based interfaces are implemented here. The application layer accesses the database through the service layer. It is different from the operator interface written by users in Fig. 1. It is usually written by the service and database developer and utilized to manage the data conveniently.

Specifically, the high level application provides physicists and engineers easy-to-use programming interfaces to access the database. Instead of having a deep understanding of the underlying database, they could simply invoke the API and concentrate on their dedicated functions. Additionally, some beam tuning applications require heavy simulation computing, a large amount of data initialization and real-time data from EPICS control system. With the API providing needed data such as computing results, formatted initialization files and values of EPICS process variables(PV), physics applications could perform their functionalities more efficiently. In conclusion, the high level application simplifies application program development, offload the heavy database query, buffers the user from the details of EPICS, and shields them from the effects of database structure changing.

More importantly, an accelerator facility is composed of many subsystems and thousands of devices. With integrating all the data such as machine configuration, lattice and model, better data consistency is ensured and data redundancy is effectively avoided. Meanwhile data sharing across multiple systems becomes more convenient. What is more, combining data from multiple sources makes it possible to utilize data mining and data analysis to evaluate the beam state in the future.

3.1. Modular design

A large number of data with various types will be generated during the design, construction, installation, commissioning as well as the operation of an accelerator. They contain structured data such as Lattice, cable and PV. They also include semi-structured data such as E-log. Definitely they involve unstructured data such as images and waveforms as well. Centralized data management will make the database too large and difficult to deploy. For this reason, we divide the data into several loosely coupled modules. Each module implements a relatively independent function. A module consists of three layers: database, service, and application as shown in Fig. 3.

The division between modules and modules is based on underlying data. There is no much duplication between modules. So a module only has one database. Services/APIs are the interfaces provided for users such as physicists to write dedicated physics applications. Applications focus on managing the data and services of the module. They are not provided for users. In general, modules and modules interact with each other through services/APIs. This could restrain from the impact of changes in the database structure. Modules of the parameter mainly used in the design phase and lattice/model used in the commissioning phase will be presented as examples in the following subsections.

3.2. A prototype module design—Parameters

A web-based parameter management system at SHINE is developed for accelerator physicists and researchers to communicate with each other and track all important physics and other equipment parameters consistently during the busy design phase. The system is based on standard J2EE (Java 2 Platform, Enterprise Edition) Glassfish platform with MySQL database used as backend data storage. The database schema is illustrated in Fig. 4.

The database saves the properties as Name/Value pairs and has built a universal database schema. It could be used not only at SHINE, but also at other accelerator facilities. To facilitate database access in the programmatic way, a set of Java entity classes for object-relational mapping (ORM) are generated following Enterprise Java Bean (EJB) standards. These EJB classes provide base interfaces for database accessing. Database query through these JPA (Java Persistence API) classes is much simpler than direct SQL with JDBC (Java Database Connectivity) API. Each database table has a corresponding entity class as direct mapping. Services/APIs are predefined database queries using Java entity classes for database accessing. They are provided to users to facilitate application programming. An example for service API is getAttribute ("name") which returns the attribute related properties stored in the database as a Java object [4]. Another example for service API can be seen as setAttribute ("name") which puts a new attribute to the database.

The user interface is built with JavaServer Faces incorporating MVC (Model, View, Controller) architecture for separating logic from presentation. Fig. 5 shows an editable table panel allowing users to view and edit parameter data in the database. Except for basic functions of query, modification, saving and deleting a record, the application also provides several other functions such as authorization, batch uploading, image uploading, history data viewing, etc.

3.3. A prototype module design—Lattice and Model

A MySQL based database has been designed for hosting lattice and physics modeling data while a set of web-based services are designed for data access. The technology for mapping Java objects to database is through JPA. We implement a series of REST(Representational State Transfer)-based services on J2EE Glassfish platform. Fig. 6 shows

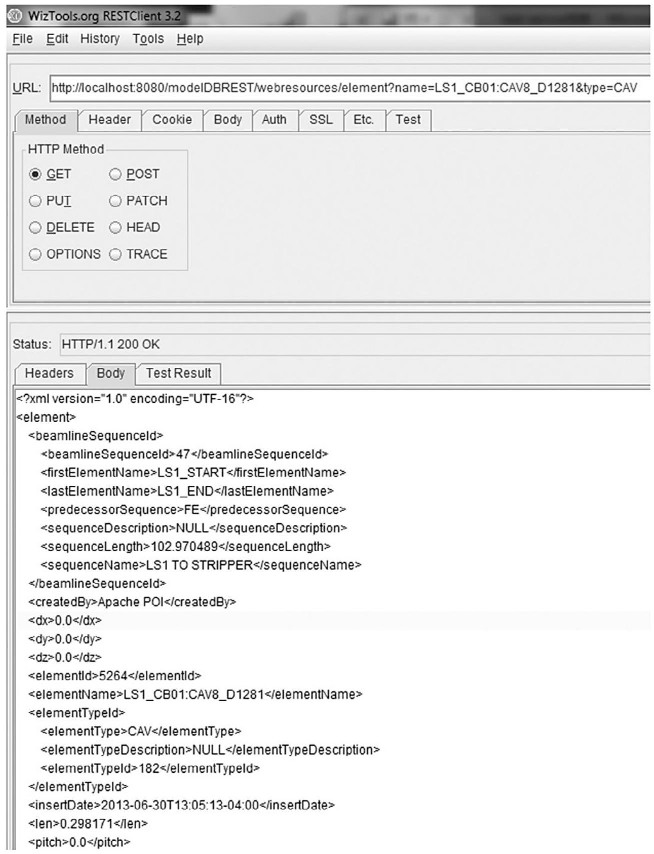

Fig. 6. Test of REST service.

a test result of a REST service output example which performs an element data query with a specified name and type. The URL for this request looks like 'http://localhost:8080/modelDBREST/webresources/element?name=LS1_CB01:CAV8_D1281&type=CAV'. The returned query is in standard XML format. Applications can then handle the XML based data with standard XML parser and renderer for further calculation or better display.

4. Conclusions

SHINE is expected to be the first hard X-ray FEL facility in China. The EPICS-based control system of SHINE is divided into four layers, among them the high level database and applications providing a platform to handle all the data generated during the design, construction, commissioning and operation. The distributed high level applications are designed with three-tier architecture: database, service and application. To facilitate development and simplify deployment, the high level database and applications are separated into several loosely coupled modules. Each module has a database as well as a series of services/APIs for data access. With the universal database schema, it could be used in other accelerator facilities as well. After all, due to the system modular design and universal database schema, it is easy to collaborate with other institutes for resources sharing. This overall control system architecture and high level applications give us the most flexibility and efficiency for SHINE control system development.

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