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STATUS OF THE SHINE CONTROL SYSTEM

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Abstract

The high-gain free electron lasers have given scientists hopes for new scientific discoveries in many frontier research areas. The Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is under construction in China, which is a quasi-continuous wave hard X-ray free electron laser facility. The control system is responsible for the facility-wide device control, data acquisition, machine protection, high level database or application, as well as network and computing platform. It will be mainly based on EPICS to reach the balance between the high performance and costs of maintenance. The latest technology will be adopted for the high repetition rate data acquisition and feedback system. The details of the control system design will be reported in this paper.

OVERVIEW

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].

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. It will utilize a photocathode electron gun combined with the superconducting Linac to produce 8 GeV FEL quality electron beams with 1 MHz repetition rate.

The control system of SHINE is responsible for the facility-wide device control, data acquisition, machine protection, high level database or application, as well as network and computing platform. 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.

According to the experience of SSRF and SXFEL, the control system of SHINE will be mainly based on EPICS (Experimental Physics and Industrial Control System) to reach the balance between the high performance and costs of maintenance. 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-scale scientific experiments.

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ARCHITECTURE

As shown in Fig. 1, the control system can be divided into four layers to ensure the performance and scalability, 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 the operators, engineers and physicists. It allows them to interact with the machine components.

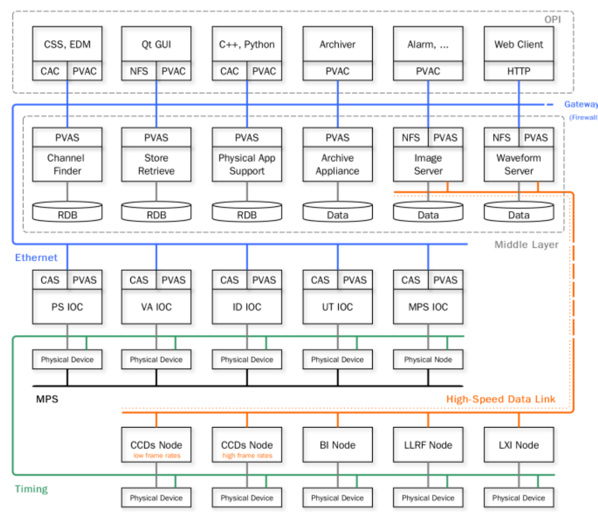

Figure 1: Architecture of the control system.

The middle layer consists of compute, storage and network devices. It provides the runtime environment for the whole accelerator control system. It also undertakes 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, such as magnet power supply control, vacuum gauge control, stepper motor control and so on. The machine protection and timing system will be also implemented in this layer. They are the basis components of the control system.

The data acquisition layer is designed for the high speed image and stream data acquisition, processing and storage. It involves the beam and laser diagnostics, microwave related system. Some custom software will be used at this layer.

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ENVIRONMENT

The central servers consist of several high performance computers, which provide the services as follows.

- EPICS Services: include the base, support modules, extensions, cross-compile support for different hardware platforms. All console computers register on the server and use the shared resources, such as display manager.
- Network File Service: provide file sharing solution for the control system. The authorized clients can view and optionally store and update files on the servers.
- Directory Services: used for the authorization of accessing various resources. The OpenLDAP will be adopted.
- Archive Services: store various runtime data for the parameters tracking and fault diagnosis. The scalar data will be achieved in the archiver appliance. The stream data will be achieved using dedicated system. The relational databases, non-relational databases or distributed file systems will be selected.
- Time Synchronization Service: use the network time protocol to synchronize the controllers, servers and console computers. It keep their internal clocks synchronized to a uniform reference time.

In addition to the above, other services are web service, backup service, software version control services, syslog service and so on.

The most services run on the virtual servers, which are highly scalable and available servers built on the cluster of physics servers. The architecture of the server cluster is fully transparent to the users. The virtual servers have been used for several years at SSRF, which improved the stability and reliability significantly.

NETWORK

The network is the important infrastructure for modern distributed control system. The performance and reliability is critical. In this project, the Ethernet will be used as the backbone of the control network. Most of hardware devices will be connected to 10 GbE access layer switches. The access layer switches have two connections to separate 40/100 GbE core switches, which is designed to ensure the reliability. The VLAN (Virtual Local Area Network) will be adopt, which divides the network into multiple subnets.

Several dedicated network will be built for the device control and data acquisition sub-system. For some high-speed cameras, point-to-point optical fiber connections will be used.

DEVICE CONTROL

The device control is mainly responsible for the magnet power supply, vacuum gauge, ion pump, stepper motor and so on, whose number will reach 10K. The IOCs (Input / Output Controllers) are the key components of the control system. All the interfaces to hardware devices will be through the IOCs. The IOCs connect the local controllers via backplane bus, filed buses or Ethernet. By using the protocol converters (including software and hardware), the devices with field buses such as RS-232/RS-485 can be reached via Ethernet.

The IOCs hardware must be COTS (Commercial Off-The-Shelf) products with the features of high performance and cost effective. The fanless industrial embedded controllers will be the best option, such as DA-68x series from MOXA or ARK-3000 series from AdvanTech.

DATA ACQUISITION

The data acquisition is mainly responsible for the image acquisition for beam profile measurement and laser diagnostics system, waveform data acquisition for beam instrumentation system (position, charge, length and arrival-time measurement), microwave related system and general LXI devices (oscilloscope and spectrum analyzer). Due to high repetition rate, the large amount and high rate of data acquisition will be challenges.

The industrial cameras support multiple buses, such as FireWire, USB, GigE Vision, Camera Link, CoaXPress and so on. The GigE Vision is a globally accepted camera interface standard developed using the Gigabit Ethernet communication protocol. It offers the greatest technical flexibility in terms of bandwidth, cable length and multi-camera functionality. The Camera Link is a serial communication protocol standard designed for computer vision applications. It is used for the higher speed connectivity.

For the majority of low fps image acquisition, the GigE Vision cameras will be adopt. The dedicated networks will be employed to transmit the images to the servers. The software will based on the areaDetector. The image processing contains image rotations, flips, ROI (Region of Interest), profiles, etc. The similar image acquisition systems has been operated for several years at SSRF and SXFEL.

For the minority of high fps image acquisition, the Camera Link cameras will be adopt. The Camera Link optical extender can be used to extend the data transmission distance over optical fiber links, as shown in Fig. 2. The software mainly focus on the image acquisition and storage. The image processing and analysis will be completed offline.

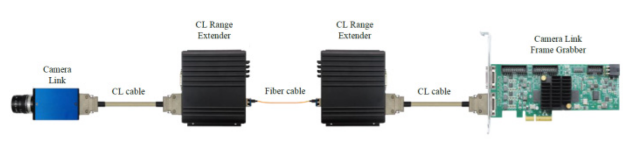

Figure 2: The Camera Link range extender.

For the LXI device, The LXI (LAN eXtensions for Instrumentation) consortium defines standard ways for Ethernet-based instruments to communicate, operate and function. The data is transmitted to the server through the dedicated network. The software will be developed via VISA (Virtual Instrument Software Architecture).

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SOFTWARE

The whole control system will be based on open-source software. The CentOS (Community enterprise Operating System) will be selected, which is a free operating system distribution based upon the Linux kernel. The major software will adopt the latest stable release series of EPICS Version 3. The components of Version 7 will be evaluated and used partially.

The most IOCs will be built with the existing records and device support modules. The StreamDevice will be used for the devices with serial communication interfaces, including RS-232, RS-485, GPIB, TCP/IP, etc. The netDev will be used for communicating with Omron and Yokogawa PLCs, s7nodave for Siemens S7 PLC. The custom IOCs will be based on asynDriver, which is a general purpose facility for interfacing device specific code to low level communication drivers.

The high level application plays an important role in the whole control system. It provides a platform to hold the information base, as well as a set of cooperating services for data access [2]. It is composed of three layers: database, service and application.

The database is a general data storage container for the machine configuration, lattice, state, alarm and so on. 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 kinds of tools and components used to display the information to users. Both web-based and desktop-based interfaces will be implemented. The application layer accesses the database through the service layer.

The free electron laser facility is composed of many subsystems. Combining data from multiple sources makes it possible to utilize data mining and analysis. The high level application provides operators, engineers and physicists easy-to-use programming interfaces to access the databases. It can simplify the application development, offload the heavy database query and shield from the database structure changes.

TIMING

The timing system provides trigger and bunch-id information to the accelerator equipment, including injector, laser, modulators, beam and laser diagnostic system. The White Rabbit (WR) technology will be evaluated.

The White Rabbit is a collaborative project including CERN, GSI, and other partners from universities and industry. It can provide sub-nanosecond accuracy and picoseconds precision of synchronization for large distributed systems. It also allows for deterministic and reliable data delivery.

The timing system is composed of master, WR switch and node devices. The master receives reference signal from the synchronization system. The switches distribute the clock to all the nodes in the network using a hierarchical architecture. The node basic functionality comes in the form of an IP Core called WR PTP Core. They can be standalone trigger fanout modules or FMC boards, which can be embedded in the DBPM and LLRF processor. The system architecture is shown in Fig. 3.

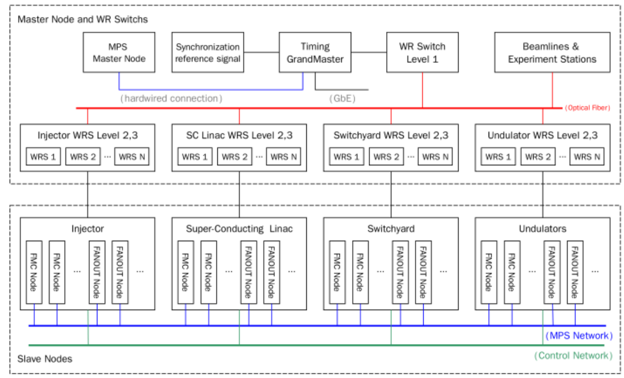

Figure 3: Architecture of the timing system.

MACHINE PROTECTION

The Machine Protection System (MPS) is designed to protect the important machine components from damage when serious abnormal situations occur. The system must be robust and reliable. It receives the interlock signals from the hardware devices, performs the protection operations and reports the status to the operator interface layer. Take the vacuum system for example, the pressure in the vacuum chamber is continuously monitored via vacuum gauges and ion pump current. The vacuum valves are controlled by the machine protection system. An interlock action will close the proper isolation valves and stop the beam in case of anomalous pressure rises.

The system will be based on the PLC + FPGA band adopts the hierarchical structure. It consists of one master nodes and several slave nodes, as shown in Fig. 4. The master node receives and summarizes the signals from slave nodes of the injector, superconducting Linac, switchyard, undulators, beamlines and experimental stations. The slave nodes control the executive devices, such as the vacuum valve and so on. The nodes are connected via optical fiber instead of cables.

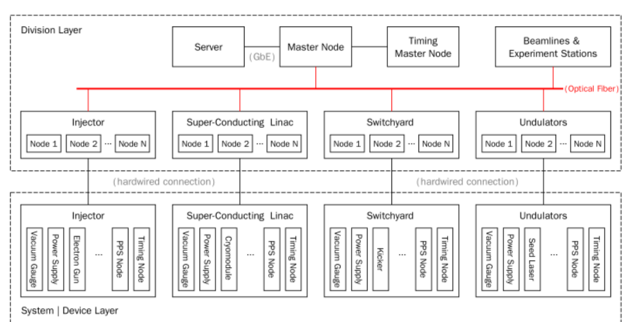

Figure 4: Architecture of the machine protection system.

CONCLUSION

The control system of SHINE will be a large scale real-time and interactive system with high reliability and stability. The large scale system integration, high repetition rate

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and the high data throughput will be great challenges. The latest hardware and software technologies need be adopted. Some research projects have begun, including system development platform, high frame rate image acquisition, machine protection system, timing and feedback system. The technical discussions and cooperation are welcome.

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