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CONSTRUCTION OF BEAM MONITOR CONTROL SYSTEM FOR BEAM TRANSPORT FROM SACLA TO SPring-8

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Abstract

As a part of the SPring-8 upgrade project, the SACLA (SPring-8 Angstrom Compact free electron LAser) linac will be used as the injector for the SPring-8 storage ring. We will upgrade the beam monitor system for beam transport, which consists of screen monitors (SCM), beam position monitors (BPM), and current transformers (CT). For the SCM, we adopted the GigE Vision standard for the CCD camera and EtherCAT as a field bus for the stepper motor control of the focusing system. We have developed camera control software using open source libraries to integrate various vendors' GigE Vision cameras with the SPring-8 control framework. A grabbed image is stored into the file server and properties, such as camera settings for image and event number, are stored into the database. The BPM is a key device for precise and stable injection. We adopted the commercially available MTCA.4 fast ADC/DAC module with modified firmware developed for the readout of the BPM and the CT. Acquisition software for MTCA.4 modules to synchronize with a beam trigger is being developed. The acquired data are stored into the database with a time stamp and an event number. The preparation of the beam monitor control system for the beam transport to injection from SACLA to SPring-8 is herein presented.

INTRODUCTION

The upgrade project, SPring-8-II [1], requires a low emittance beam for the injection because of its small dynamic aperture. The SACLA linear accelerator to be used has been designed as a full-energy injector for the SPring-8 storage ring, sharing with the XFEL operation. Then, an ultralow emittance electron beam with a short bunch length of 10 fs is delivered from SACLA. The frequency of beam injection into the SPring-8 storage ring is 10 Hz for an initial injection and once a few minutes for top-up operations, while the repetition rate of the SACLA linac is 60 Hz. The beam transport from SACLA to SPring-8 storage ring is about 600m. The beam monitor system has approximately 30 screen monitors (SCM), 30 beam position monitors (BPM), and 10 current transformers (CT). The beam monitor and its control system will be upgraded for the beam transport from SACLA injection.

In SPring-8, image diagnostic systems such as SCMs, widely use charge-coupled device (CCD) cameras with Camera Link interfaces (I/F) [2]. The image processing system was developed and operated based on a PC server or MicroTCA that supports the Camera Link I/F [3-5]. The Camera Link I/F has high bandwidth data transfer capability, trigger synchronization, and camera control via a serial bus. As grabber boards were released by multiple vendors and Linux APIs were available, the Camera Link standard was adopted when switching from analog cameras to digital cameras for SCMs approximately 10 years ago. However, the Camera Link I/F has a maximum data transfer length of 10m, which is too short for use in an accelerator facility; therefore, a transmission/reception device is required. The disadvantage of the Camera Link I/F is that it requires complex cabling with a chain of transmitters and receivers using optical conversion. This results in difficult and expensive maintenance. In the next phase of SPring-8, to identify an alternative, the GigE Vision [6] standard camera was evaluated. This would allow data transfer lengths of up to 100m, and significantly simplify cabling.

For the readout electronics of the BPM, two candidates are selected; our original design based on MTCA.4 [7] and Libera Spark [8]. They are developed and evaluated in parallel. The MTCA.4 based electronics is the same as the new low-level RF system [9] and it uses the commercially available MTCA.4 fast ADC/DAC module. This will also be used as the readout electronics of the CT.

NEW CONTROL SYSTEM FOR BEAM MONITOR

GigE Vision Camera

Post evaluation, the GigE Vison camera has been adopted for the SCM. The camera control software has been developed using open source libraries to integrate in the SPring-8 control framework. A PC-based image processing system is built to control the SCM with one unit by installing PCI Express cards such as Power-over -Ethernet (PoE) type network interface and trigger counter. Details of the development are described in the next section. The JAI Go-2400M (Fig. 1), which is a GigE version of the same series as the Camera Link camera used in SACLA, is used.

Figure 1: JAI Go-2400M.

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EtherCAT

EtherCAT is adopted as the standard field bus of Spring-8-II. It is used for slow control of the equipment, such as the magnet power supply control, an RF system, and a new in-vacuum undulator (IVU-II) system [10].

In new SCMs, the EtherCAT will be used to control the stepper motors such as screen operation and lens focusing system. The EtherCAT modules are wired in a daisy chain topology with Ethernet cables. The reduced wiring is one of the advantages of EtherCAT. By using a PCI Express type EtherCAT master card, a one-unit control system including camera operation can be built.

MTCA.4

As the VME market tends to shrink, the VME is replaced with MTCA.4 for high speed digital signal processing. For the readout electronics of the BPM and CT, the commercially available MTCA.4 fast ADC/DAC module with modified firmware development is adopted [9]. A schematic drawing is shown in Fig. 2. The signals of two BPMs and two CTs are transferred to the 10-channel digitizer advanced mezzanine card (AMC).

The acquisition software for MTCA.4 modules to synchronize with a beam trigger is being developed. The acquired data are stored into the database with a time stamp and an event number.

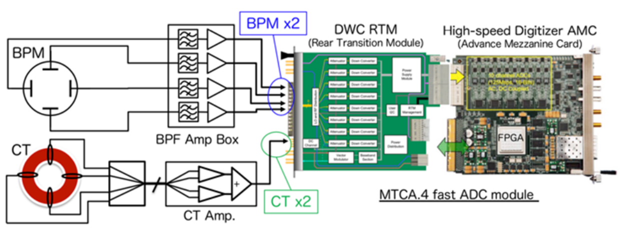

Figure 2: Schematic diagram of the MTCA.4 based readout electronics for BPM and CT.

GIGE VISION CAMERA CONTROL

Earlier models of the GigE Vision camera were available only with Windows software; only some vendors provided a software development kit (SDK) for Linux. For this reason, it was developed as a dedicated software, and become individual support within the SPring-8 control framework [11]. The problem was that the selection of cameras was limited and long-term maintainability was inferior.

In recent years, a general-purpose open source library for GigE Vision has become available. Therefore, camera control software was developed using open source libraries to integrate various vendors' GigE Vision cameras with the SPring-8 control framework. The aim is to use the GigE Vision camera in the SCM upgrade in the beam transport from SACLA to SPring-8.

Development Policy

Many vendors supply some form of SDK for end users to control GigE Vision cameras, but using one of these SDKs has some disadvantages:

- Most vendors' SDKs are tied to their own camera restricting the use of other vendors' cameras.
- While the SPring-8 control system is UNIX-based, many SDKs provided by camera vendors target Windows and are difficult to integrate.
- Most vendor-supplied SDKs are proprietary software, making debugging of problems more difficult.

These factors prompted a search for an open source library that could control any GigE Vision camera, run on Linux, and be integrated into SPring-8 control framework. The SPring-8 control framework [11] is divided into a GUI layer that performs control commands, and a device control layer that controls hardware, and sends messages via the message server (MS). A software called equipment manager (EM) runs in the device control layer.

At present, Camera Link I/F cameras are the mainstream for SPring-8 diagnostic imaging systems. The camera control EM has been developed to support cameras from various vendors. In the screen monitor, EM is responsible for camera control and image storage; the GUI performs image analysis, such as beam profile measurement.

The development policy of the GigE camera control system provides basic camera operations as general-purpose EM functions, and the image analysis uses an existing GUI. This allows one to build the camera control EM by simply specifying an IP address or hostname in the EM configuration file without programming. The goal is to realize a system that could be replaced with a Camera Link camera.

GigE Vision Standard and Aravis Library

Most Gigabit Ethernet cameras conform to the GigE Vision standard, which uses the GenICam (Generic Interface for Camera) [12] standard to describe the features supported by the camera. The GenICam standard provides a common interface for many types of cameras across different vendors and physical connections. The camera provides an XML file that describes the functions it supports and how they map to the registers on the device. As the XML file describes the camera control method, it is possible to support cameras from various vendors.

Aravis [13] is a glib/gobject based open source library that conforms to the GenICam standard, including GigE Vision. The current latest version is 0.6, which supports GigE Vision and USB3 protocol cameras. Basic parameters such as exposure time, gain, ROI, and binning are available for camera settings. A simple camera simulator and image viewer are also provided.

Figure 3 shows the connection test with the camera. It was confirmed that the camera operation and the image acquisition were possible with multiple vendor cameras such as JAI GO-2400M, Basler acA780-75, and Leutron Vision PicSight P202M. It was also confirmed that the camera does not support the original functions. In the current version, the original functions such as parameter saving,

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IP address setting, and camera test pattern output cannot be used. Although these functions are necessary for the initial setting at the time of camera installation, they can be handled by vendor software. Therefore, there is no problem in operation after installation.

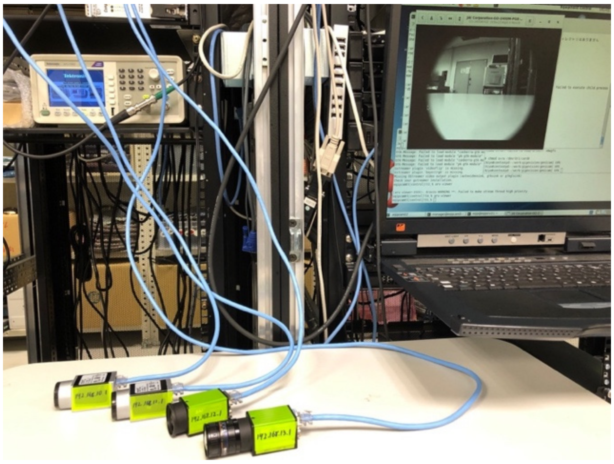

Figure 3: Initial camera test using Aravis.

Camera Control EM and Data Acquisition MDAQ

An EM function for GigE camera control was prepared. The Aravis library provides functions for setting and obtaining basic camera parameters, such as exposure time, gain, ROI, and binning. Using this library, 'put' and 'get' EM functions for each parameter were created. Figure 4 shows an example of the EM configuration file (config.tbl). This allows us to build the camera control EM by editing the camera IP address or host name in the argument part, without any programming.

```
put/sr_mon_gigecam_param
  trigmode_%d      em_cntl_gigecam_put_triggermode      "192.168.10.1"
                   none
                   em_std_ret
  exposure_%d      em_cntl_gigecam_put_exposuretime     "192.168.10.1"
                   none                                  IP address or HOSTNAME
                   em_std_ret
  gain_%d          em_cntl_gigecam_put_gain             test-camera-10
                   none
                   em_std_ret

get/sr_mon_gigecam_param
  exposure         em_cntl_gigecam_get_exposure         "192.168.10.1"
                   none
                   em_cntl_gigecam_ret_int
  gain             em_cntl_gigecam_get_gain             test-camera-10
                   none
                   em_cntl_gigecam_ret_int

get/sr_mon_gigecam_grab
  image            em_cntl_gigecam_get_image_onefile    test-camera-10 [dir] [name]
                   none
                   em_cntl_gigecam_ret_int                              HDF5 file
```

Figure 4: An example of EM configuration file.

Image data is written on an NFS disk. The data format is HDF5 (Hierarchical Data Format release 5) [14]. As HDF5 can classify data into groups and handle them hierarchically, two-dimensional image data and meta information such as camera name, image size, gain, exposure time, trigger number, and timestamp are stored in one HDF5 file. The image data file in this case has the same data structure as the current image processing system of the SACLA screen monitor [5].

In the accelerator beam diagnostic system, screen monitor imaging is performed in synchronization with the beam. Image data acquisition synchronized with the beam trigger was realized by MDAQ [15], which is the new DAQ system of SPring-8 control framework. The procedure of image data acquisition is as follows:

1. Camera selection
2. Specify run type
3. Specify the number of recordings
4. Send recording start command

Control parameters related to image acquisition such as camera selection, run type, number of recordings, and recording start are shared between EM and MDAQ using Shared Memory. MDAQ executes the imaging process in synchronization with the trigger, and when a recording control command is sent from the GUI via EM, it saves the pre-set number of HDF5 files.

APPLICATION TO BEAM MONITOR

The renewal of the beam monitors (SCM, BPM, CT) in the beam transport line is scheduled in 2020. Prior to the monitor update, two units of SCM were replaced this summer, and a beam test will be performed in operation starting from autumn 2019. We have installed two GigE Vision cameras and one PC-based image processing system for the screen monitor.

Apply to Screen Monitor Control

The configuration of an SCM is shown in Fig. 5. The SCM system consists of a screen, screen actuator, an optical system, and an image processing system with a camera. As the beam is destructed by the screen, the screen actuator moves the screen outside of the beam orbit when it is not in used. The material of the screen components is an alumina fluorescent screen, and Ce:YAG scintillator. For the camera, JAI Go-2400M-PGE (2.35 Megapixel CMOS Monochrome, GigE Vision, PoE) was selected.

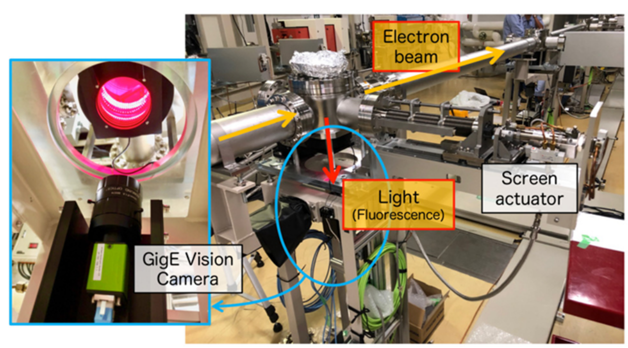

Figure 5: Screen monitor for SSBT.

The GigE camera control computer is equipped with a PoE type network interface board (Neousys tech. PCIe-PoE354at) and a trigger input counter board (Gopher ax-pcie3901). Ubuntu16 server for 64-bit PC is used as the operating system. As Gigabit Ethernet has a maximum transmission distance of 100m, the GigE Vision camera is directly connected to a computer with a local network and operated with PoE power supply control.

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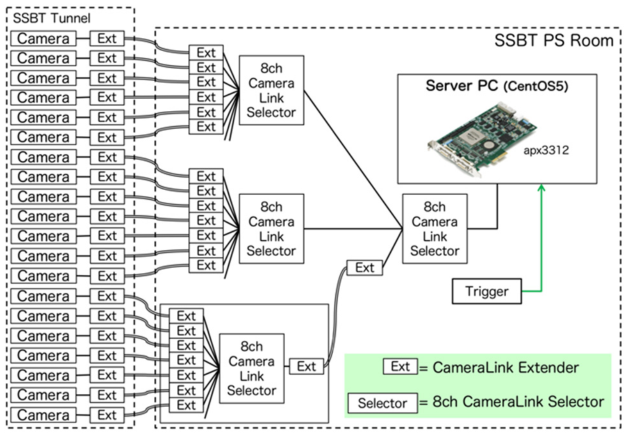
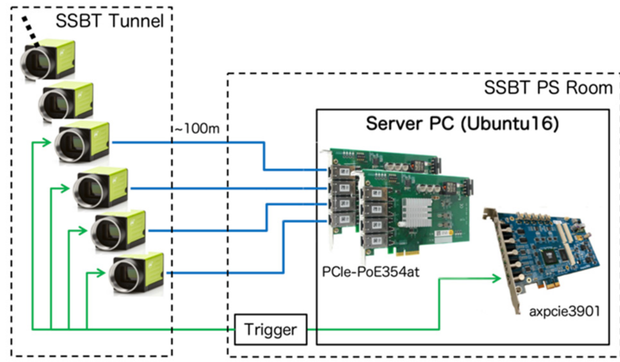


(a) Current Camera Link camera connection



(b) Future plan: GigE camera connection

Figure 6: Schematic view of camera connection, current and future.

The current image processing system of SCM in the beam transport SSBT is built with the Camera Link camera, and it has a complex structure combining Camera Link extenders and selectors as shown in Fig. 6 (a). The image processing system using GigE Vision cameras, and a simple structure is realized, as shown in Fig. 6 (b)

Device Setup

Neousys tech. PCIe-PoE354at [16] is a PCI Express x4, Gen2 4-port Ethernet board that supports PoE power supply. The vendor provided a Linux driver source and library binary file (libwdt_dio.so) for PoE power supply control. The PoE power supply control uses SMBus to send signals from the PCI Express slots, the motherboard must support it. With the Supermicro server computer that was adopted, PoE power supply control for each port became possible by enabling the jumper pin of “SMBus to PCI Slots”. In addition to the GigE camera control, an EM function for PoE power supply control of the PCIe-PoE354at board was developed.

Gopher's axpcie3901 is the PCI Express version of the high-speed counter CompactPCI board axcpci3901 [17] with a 4ch 32 bit counter. The input signal level is TTL or NIM, and the pulse input up to a frequency of 200 MHz can be measured. There was a Linux driver for 32-bit OS, which was used with CentOS5. The driver was modified to support 64-bit OS and for use on Ubuntu16.

Beam Operation

Two SCMs with GigE Vision cameras have started operation since the end of September 2019. A GUI was created as shown in Fig. 7, and operations were performed for each camera, including image acquisition and profile analysis. A grabbed image is stored into the file server in HDF5 format. The meta information such as camera settings for image and event number, is stored together in the HDF5 file, and it will be stored into the database in the future.

At the beam study time before user operation, the new screen monitors system in both current injection and SACLA injection were tested.

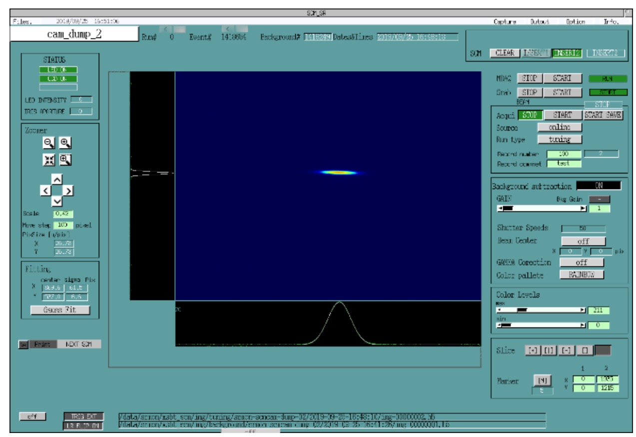


Figure 7: Operation GUI for screen monitor.

SUMMARY

In preparation of the beam injection from SACLA, a control system for monitoring equipment such as SCM, BPM and CT, has been created. We are developing and evaluating GigE Vision camera image processing system for SCM and MTCA.4 system for BPM and CT.

For SCM, the GigE Vision camera was installed prior to the upgrade plan. The camera control software was developed using the Aravis library to integrate various vendors' GigE Vision cameras with the SPring-8 control framework. A system to control the SCM with one unit by installing PCI Express cards, such as PoE type Ethernet and trigger counter, has been built. The GigE camera image processing system can be expanded in the future to control many cameras with SCM upgrades.

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