BEAM PROFILE MONITORING SYSTEM FOR XFEL/SPRING-8

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Abstract

A beam profile monitoring system was developed for XFEL/SPring-8. In this paper, we focus on an image processing system. The image data can be recorded with the synchronized data acquisition system of XFEL/SPring-8. The system is composed of 46 screen monitors (SCMs) and the transverse size and shape of the electron beam are measured down to a resolution of 10 µm. The SCMs provide a valuable tool for beam commissioning in terms of optimization of beam transport and measurement of beam emittance. The imaging system uses CCD cameras that are connected by Camera Link. An image data is selected using the Camera Link selectors and is then processed by an image server. A diagnostic tool for the beam profile monitoring system requires many functions: real-time image monitoring, image analysis, camera control, screen control, etc. We developed a GUI (Graphical User Interface) using Python as a tool to flexibly implement the functions required for the image data. The system was successfully implemented on the SCSS prototype accelerator and it operated as intended. The system can thus be applied to the beam commissioning of XFEL/SPring-8, which is planned for March 2011.

INTRODUCTION

The Japanese X-ray free electron laser (XFEL/SPring-8) is under construction at the SPring-8 site, and its beam commissioning will begin in March 2011 [1]. XFEL/SPring-8 will generate an X-ray laser with a wavelength that is less than 0.1 nm via the SASE (Self-Amplified Spontaneous Emission) process. To achieve this goal, high-precision beam characteristics (a low emittance electron beam less than 1 π mm mrad, etc.) are required, and various types of beam diagnostic tools must be positioned at each stage of the accelerator [2]. In total, 57 RF cavity beam position monitors (RF-BPMs), 49 screen monitors (SCMs) for beam profile measurement, and 35 current transformer (CTs) for beam charge measurement will be installed.

In this paper, we describe an image processing system equipped with 46 SCMs that is used for transverse beam profile measurement with an accuracy of about 10 µm. The remaining 3 SCMs are used for longitudinal beam profile measurement, which will not be addressed here.

The beam profile monitoring system plays the important role of tuning the beam during the beam commissioning. The system is used for optimization of the beam transport and the measurement of beam parameters (emittance, twiss parameters, etc.). In order for the beam commissioning of XFEL/SPring-8 to proceed smoothly, a prototype of the system has been developed and was implemented in the SCSS prototype accelerator to confirm its performance.

SCREEN MONITOR (SCM)

The configuration of an SCM is shown in Figure 1. The SCM system is composed of a screen, a screen actuator, an optical system, and a data acquisition system with a CCD camera. Since the beam is destructed by the screen, the screen actuator moves the screen outside of the beam orbit when it is not used. The material of the screen components was selected depending on the beam energy. For higher energy (>30 MeV), metal foil was used for the optical transition radiation (OTR) while for lower energy (<300 MeV), Ce:YAG was used for fluorescence. In order to achieve a high position resolution, the optical system is equipped with a custom-made lens. The zoom range can be adjusted through the operation of a motor. The position resolution is about 3 µm at a magnification of four times and satisfies a required resolution (10 µm). For equipment controls such as stepper motor controller of the zoom adjustment, Programmable Logic Controllers (PLCs) are used [3]. Two types of CCD cameras are used: a JAI CV-A10 CL (monochrome, 0.46 M pixel, 60 fps) and a JAI CV- M4+CL (monochrome, 1.45 M pixel, 24 fps). For each SCM, the proper CCD camera was selected according to its needs.

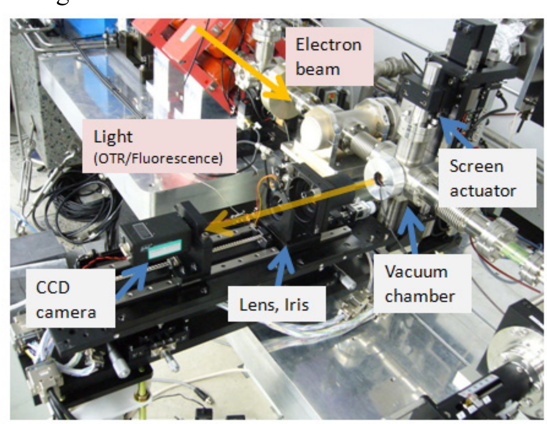

Figure 1: Screen monitor for XFEL/SPring-8.

IMAGE PROCESSING SYSTEM FOR SCM

An overview of the image processing system for SCM is shown in Figure 2. Communication with CCD cameras

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is performed by Camera Link, which makes it possible to transmit image data, provide trigger signals, and control the cameras. Measurement can only be performed with a camera because the SCM destructs the beam. Therefore, Camera Link selectors (Stack: CLS-900A) are used to select a camera, and the selection signals are inputted into an image server. In total, 11 Camera Link selectors are used to select a signal from among 46 CCD cameras. Cameras are positioned along the accelerator tunnel and the signal cables need to extend into a control room. For this reason, Camera Link signals are converted into optical signals for long-distance transmission.

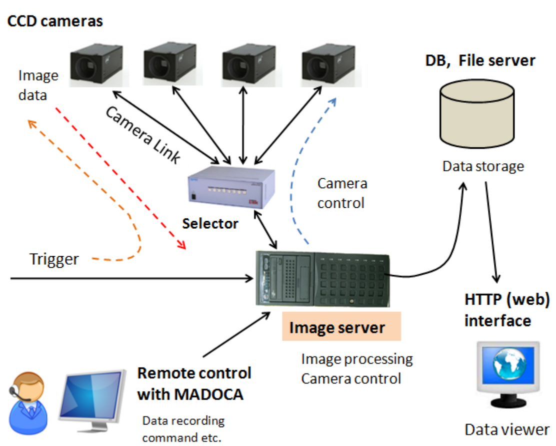

Figure 2: Overview of image processing system.

The image server has two trigger inputs for synchronization of the data acquisition system. One is for a trigger signal that activates the timing of the RF control equipment (60 Hz at maximum, called the RF trigger), and the other one is for a trigger signal for the beam arrival timing (called the beam trigger) [4]. The beam trigger is a sub-divided signal of the RF trigger. The beam trigger is used for data acquisition by the CCD cameras. The RF trigger is used to count identification numbers (called tag numbers) for the synchronization of the data acquisition.

In the image server, an image processing board (AVALDATA APX-3312/1) and a counter board (Interface PEX-632102) are implemented. These are PCI express boards, and Linux drivers are available. Cent OS 5.4 is used as the operating system of the image server. Most of the operations (camera control, image processing, etc.) are performed by the image server, though remote controls can also be applied with a MADOCA framework [5]. Sometimes the image data needs to be taken under changed conditions (the magnetic field values for beam transport, etc.). In such cases, it is useful to be able to operate the data recording remotely.

The data is stored in data storage and can be utilized for analyses. Web interface is available via the data viewer. Due to the large size of the image data, the file names of the image data are saved in the DB (database) and the image data themselves are saved in files.

Software configuration

As shown in Figure 3, the software used for image processing has a multi-layer configuration to intermediate shared memory. Higher level applications (image monitoring GUI, image recorder) send the control commands and receive data (image data, tag numbers, etc.) via shared memory, and a program for image processing and counter boards is operated via the shared memory. Such a system with shared memory has several distinct merits:

- Past image data can be obtained by preparing a buffer area for the image data in the shared memory.
- Multiple processes can utilize image data in the shared memory asynchronously. When the GUI monitors an image, the data can be recorded at the same time.
- Image data other than Camera Link can be easily processed through modification of the program for image processing and counter boards. For example, it was possible to test the system using pseudo data. In future, it will also be possible to process image data for a GbE camera.

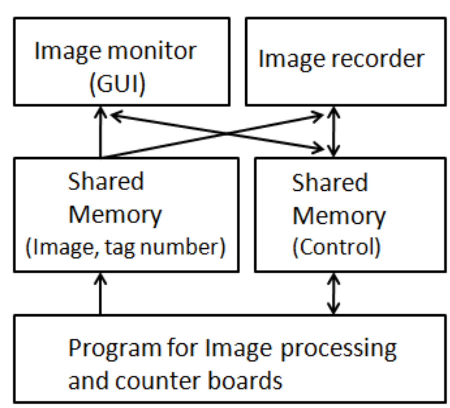

Figure 3: Configuration of software for image processing.

Using Python for GUI construction

Because many functions are implemented in our GUI, its efficient construction is a priority. For this purpose, we implemented Python and WxPython for use in the GUI toolkit. With Python, current existing modules can be easily applied. PIL (Python Imaging Library) and numpy (scientific computing with Python) are especially useful. Several modules (MADOCA control, image analysis, etc.) were prepared for possible use and were utilized to construct the GUI efficiently. In the construction of the GUI, the GUI frame was built using WxFormbuilder and the layout of the GUI frame was saved in an XRC file (XML format). With the XRC file, the development of the

GUI FOR BEAM PROFILE MONTIOR

The GUI for the beam profile monitor is used for camera tuning and data recording, and for the image viewer. The image data is recorded with synchronization of the data acquisition system in order to compare the image data with other beam diagnostic data (BPM, CT) from a beam shot. For this purpose, a prototype GUI was developed and implemented in the SCSS prototype accelerator, as shown in Figure 4. The test results, which are described below, confirmed that the system can be applied to XFEL/SPring-8.

Camera tuning

The parameters for the CCD cameras were tuned for exposure time and gain setting before measurements were taken. Tuning can be performed for each camera by selecting a camera using the Camera Link selectors. Screens can be operated in order to see the beam profile image. The tuned values for each camera are stored in the DB and can be loaded at a later time as needed. Background image data can be taken with internal trigger events and utilized for the subtraction. The threshold value for the image data can be also adjusted. After tuning, it is possible to put a lock on the tune values to prevent them from being modified.

Image viewer

Real-time beam profile images can be monitored on the GUI. Beam statistics (center, width, and intensity) and projection histograms can be obtained at the same time, as shown in Figure 4. The monitor rate of 5 Hz is sufficient to enable the beam condition to be evaluated by eye. Beam statistics can be extracted using several slice method options. In the experiment, we initially had trouble seeing the beam shape due to its small size, and therefore developed the GUI to provide expanded image data if necessary. In addition to real-time images, image data stored in the shared memory and image files can also be selected for the monitor in the same manner as above.

Data recording

Image data can be recorded on the GUI. The recording number can be set in advance. To implement the image data in the synchronized data acquisition system, the image data are stored with tag numbers. Since the image server only counts the RF trigger, we need to estimate the offset value in order to extract the tag numbers. To do this, we saved the count number of the RF trigger with a timestamp and compared the data in terms of the relationship between a tag number and the timestamp stored in the DB. We confirmed this procedure with SCS and a reasonable correlation was observed between the

GUI frame and GUI algorithm were kept separate, which simplified the construction process.

BPM data and the beam position obtained from the beam profile image.

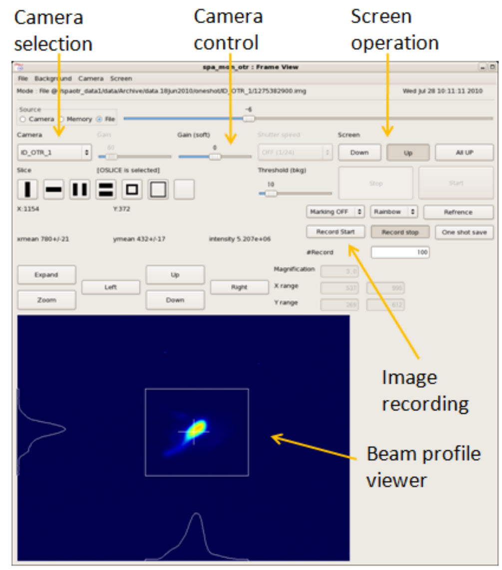

Figure 4: GUI for beam profile monitor implemented in SCSS prototype accelerator.

SUMMARY

A beam profile monitoring system was developed for XFEL/SPring-8. In the system, CCD cameras are connected by Camera Link and the beam profile image is processed by an image server. The image data is recorded with a synchronized data acquisition system in order to be able to see the correlation with other beam diagnostic data obtained from a beam shot. A prototype of the system was tested with the SCSS prototype accelerator, and we confirmed that the system can be applied to XFEL/SPring-8. We are now in the process of constructing the system for XFEL/SPring-8 in preparation for the beam commissioning planned for March 2011.

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