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Image Acquisition and Processing at the Swiss Light Source

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The integration of all devices under one coherent control system based on EPICS is an important consideration at the SLS. On the other hand, image acquisition and processing is a daily activity for devices in the accelerators, beamlines and experimental stations. Currently, we have developed two approaches, under EPICS, for image acquisition and processing. One is based on an analogue camera with a VME frame grabber connection, and the other is a Firewire (IEEE1394) CCD camera interfaced to a Linux PC. Both approaches allow to control the relevant camera parameters and to perform basic image processing. We report here on our approaches, applications, conclusions and future work.

BACKGROUND

The SLS consists of three electron accelerators (Linac, Booster and a Storage Ring) and several beamlines spread around the accelerator ring. Synchrotron light emitted by the electron beam in the Storage Ring is used at the beamlines for various experiments.

Every year the number of beamlines increases. Each beamline consists of specialized devices to suite unique requirements. All of the devices, which belong to the accelerators and beamlines, are integrated under one coherent control system based on EPICS [1]. An initial control system requirement was the video camera based systems support, for image acquisition and analysis. These systems were used mainly for the visualization of certain beam properties such as: shape, position and profile. Currently, the number of Image Acquisition and Processing (IAP) applications has increased to be able to satisfy the vast requirements of the beamlines.

The aim of this paper is to present the IAP systems at the SLS, their approaches, features and applications. First, we will describe the early IAP approach for systems based on analogue cameras and frame grabbers. Next, the systems based on Firewire cameras will be presented.

ANALOGUE CAMERAS

The first IAP application was the Screen Monitors (SM) for the diagnostics system. The aim of the application is to capture and process the beam image. This enables to obtain various beam parameters such as its position, shape and profile. The core of the SM system is an analogue camera interfaced to a frame grabber. The camera is equipped with a motorized system for the zoom and iris control. In addition, it has inputs for the trigger and shutter control signals. The image capture cycle for the analogue camera is synchronized with the 3 Hz SLS global timing system. Currently, there are approximately 20 monochrome cameras installed in the SLS. The cameras conform to the EIA standard, which defines an image size of 640x494 pixels.

The frame grabber is a PCI Mezzanine Card (PMC) module, which resides in the VME master card. The frame grabber is equipped with three independent image acquisition ADC channels, each one having a dedicated 4-way multiplexer. Such a configuration is able to support up to twelve cameras connected to a single frame grabber.

Software wise, the SM system runs under the VxWorks kernel and EPICS. Primarily, EPICS version 3.13.x was not well suited for large data transfers such as images. In order to overcome this limitation, each captured image is sent as a collection of lines from a server to client applications. Unfortunately, this approach slows down the image transfer rate. EPICS version 3.14.x does not have this limitation.

Due to the rapid development of CCD camera’s technology, the analogue camera approach seems to be obsolete for future applications.

FIREWIRE CAMERAS

Firwire (IEEE1394) is a very fast external bus standard that supports data transfer rates of up to 400Mbps in IEEE 1394a, and up to 3.2 Gbps in IEEE1394b. A single IEEE 1394 port can be used to connect up to 63 external devices. In addition to its high speed, IEEE1394 also supports *isochronous data* - delivering data at a guaranteed rate. This makes it ideal for devices that need to transfer high priority data in real-time, such as video devices. The IEEE1394 bus supports both Plug-and-Play and hot plugging, and also provides power to peripheral devices [2].

Many new cameras are equipped with Firewire interface. These cameras are more preferment, offering more valuable features in comparison to traditional analogue cameras. In order to fulfill all requirements in the SLS, it was decided to integrate the Firewire cameras to the existing control system.

EPICS SERVER

Epics Server: Introduction

Recent development in EPICS (3.14.x) has allowed for an operating system independent implementation. We decided to benefit from interfacing a Firewire camera to an EPICS server running on a Linux PC. Linux offers open source libraries that support Firewire devices, thus it appeared to be well suited for the camera integration. In addition, an X windows (motif) application was developed to provide a live feed from the camera by reading the image waveform. In the following, we explain software and hardware aspects, and typical applications of Firewire camera based systems at the SLS.

Epics Server: Server side

EPICS based image acquisition server depends on several software components which can be dynamically loaded to the Linux kernel at run time. The layered architecture of the EPICS server is presented in Fig. 1.

Recent Linux kernels (> 2.4) are coming with built-in IEEE1394 modules [3]:

- ieee1394: Core of the IEEE1394 subsystem.
- raw1394: Higher level driver module for bus access.
- video1394: Fast DMA frame transfer driver.
- ohci1394: Low level host card driver.

At the user space level, Libraw1394 is a library that provides access to the raw1394 bus module [4] and Libdc1394 is a high level API [5].

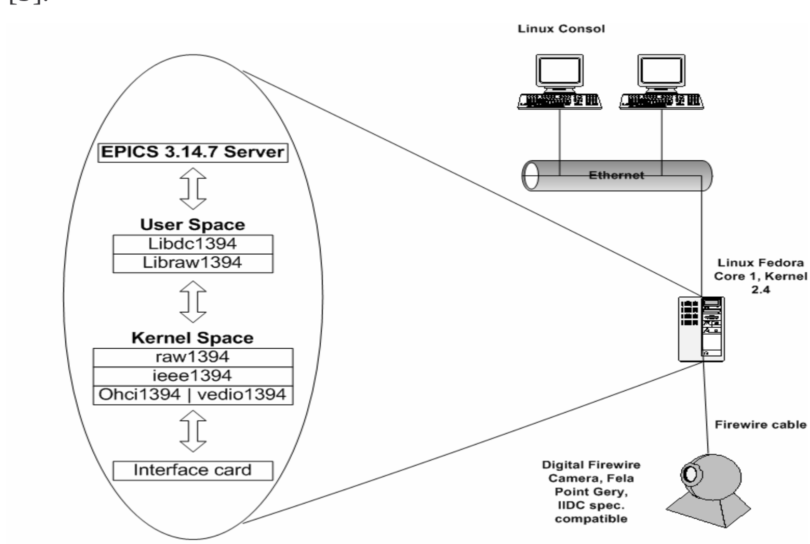


Fig 1: Camera integration schematic

EPICS device support uses non-polling (blocking) DMA capture functions for image acquisition [6]. An image acquisition process is repeated periodically. First the single image is captured, processed and then placed in the waveform. Any Channel Access (EPICS) based application can retrieve an image from the waveform.

Moreover, the server performs on-line centriod finding algorithm, background subtractions, averaging (i.e. improves signal-to-noise ratio), maximum pixel intensity calculation, standard deviation, and calibration.

Epics Server: Client side

An medm GUI is used to control the camera and EPICS server parameters, such as start/stop image transmission, region of interest selection, frame rate, shutter gain and threshold control. It also shows both vertical and horizontal distributions of the images pixel intensity, and includes an image save option (Fig. 2).

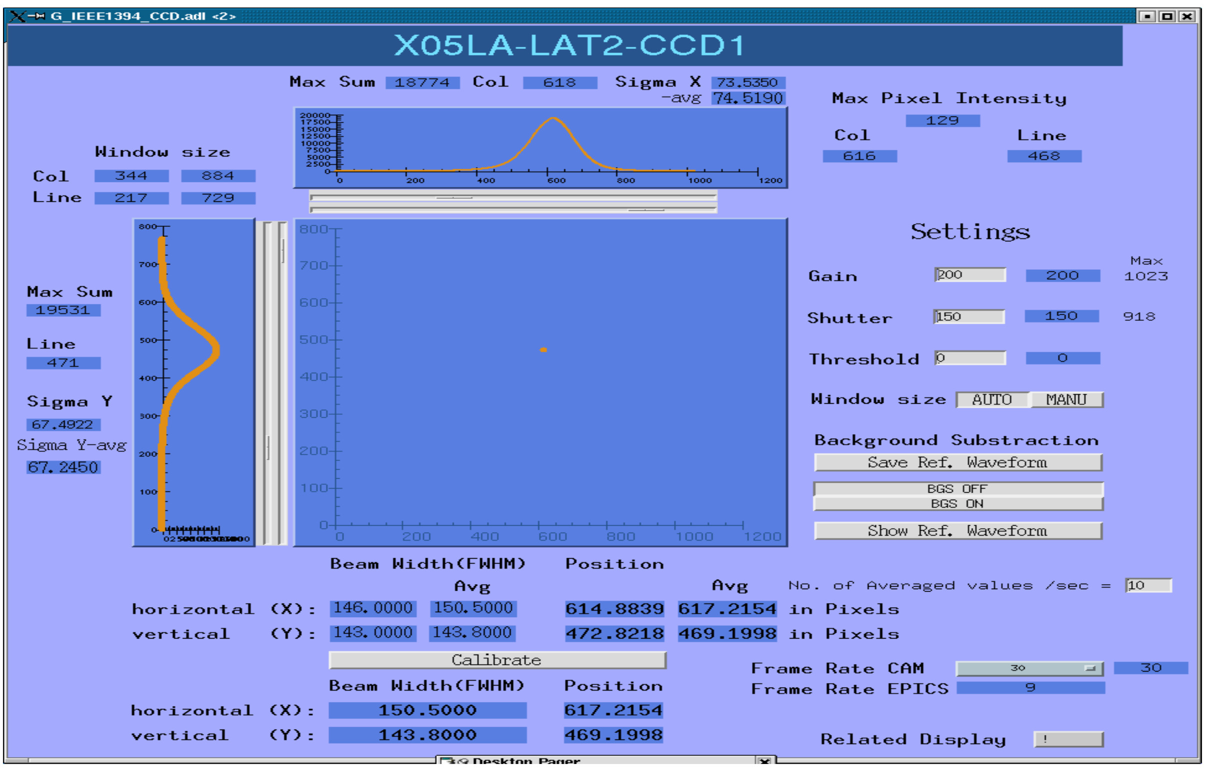


Fig 2: (MEDM GUI)

A motif based application is used to display captured images in live mode. The application uses Channel Access libraries, therefore it is already integrated with EPICS. The application displays the images which are stored in the waveform channels on the server side. EPICS monitoring mechanism enables the client application to display newly acquired images when the waveform updates. The application can display monochrome and color images. Users can choose one of many color interpolation algorithms for Bayer color representation at run time (Fig. 3).

Fig 3: Display of the X windows Application

Epics Server: Hardware Description

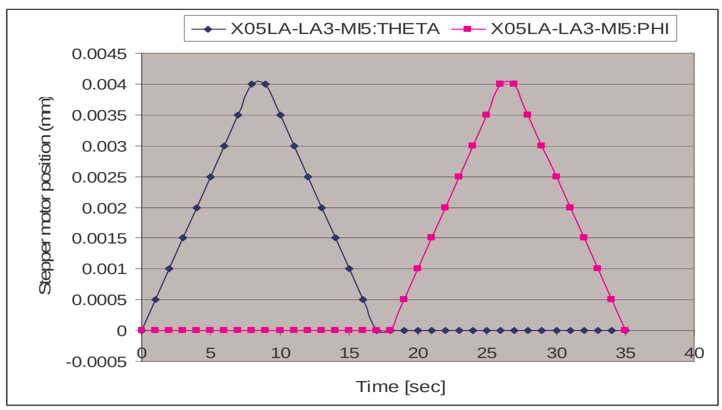
We are using a compact desktop (Barebone) called Pundit and Pundit-R, both manufactured by ASUS. This desktop is about a third of the volume of a conventional desktop PC. It has high-speed processing power with 2.8GHz Pentium 4 CPU and 1 GB RAM. The motherboard has a built-in Open Host Controller Interface (OHCI) compatible Firewire card with 6-pin port [7].

The Camera is a Point Grey Flea which is compliant with IIDC 1394-Based Digital Camera Specifications (also know as DCAM spec). This specification describes a CSR - Control and Status Register - layer on top of IEEE1394. The camera resolutions varies from a low of 640x480 to a high of 1024x768 pixels, it support frame rates from 1.875 up to 60 fps. It can use internal soft triggers or be triggered externally, this allows for synchronizing with other subsystems. The camera size is small, 30mm x 31mm x 29mm, this helps mounting it in crowded as well as not easily accessible locations [8].

Epics Server: Applications

Laser Beam Characterization and Tracking

For the FEMTO project Laser beam, the software is operated in two modes: autocorrelation mode and beam characterization mode [9]. Both modes provide information about the quality of the beam and its stability (Fig. 2). Figure 4 shows the software usage in practice, where the relation between mirror actuators motion and CCD readouts is plotted.



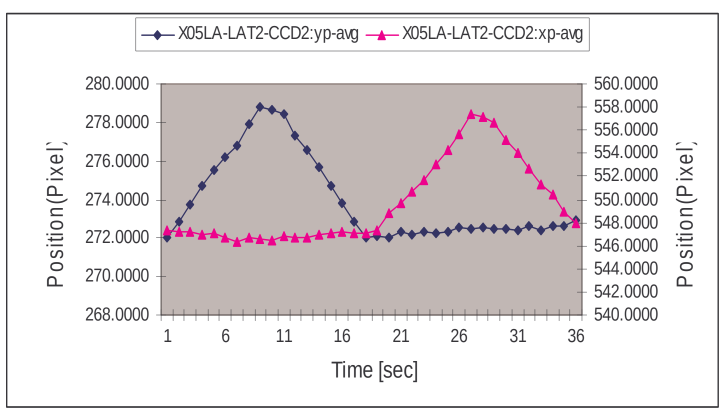


Fig 4: The relation between the actuators of MI5 and the readouts of the CCD camera in vertical and horizontal axes.
1 µm displacement corresponds to 2.5 pixels on MI5 Phi, and to 1.8 pixels on MI5 Theta (the 1.4 factor is because the laser beam enters at an incident angle of 45° on MI5).
Pixel size is 4.65 x 4.65 µm.

FEMTO Slicing Laser Stabilization Feedback

The FEMTO laser focus point - where the electron and laser beams interact - is approximately 45 meters away from the laser source. With 4 mirrors along the laser path, there are many potential causes for laser drift (laser source, optical components, temperature). A laser monitoring system based on Firewire digital cameras was implemented. The image is grabbed, processed and the center of mass is calculated. A feedback system will use this information and adjust the mirrors accordingly to compensate for the drift. Thus it will maintain optimal electron and laser beams interaction conditions.

X-ray Beam-position Monitoring

Critical information about the X-ray beam shape, profile and position is extracted. The setup used at the micro Absorption Spectroscopy (mXAS) beamline includes a scintillator that converts x-rays into visible light, lenses that enables to change the field of view and thus obtain higher resolution, and a Firewire digital camera [10].

Beamline Equipment Commissioning

Commissioning of beamline optical components, using synchrotron light, such as monochromator crystals parallelism tests is an example of an application. Furthermore, stability of the synchrotron light and determining eventual sources of vibration are also sought.

Live feed

The client application is used to display a live feed of the monitored subsystem.

Epics Server: Results

The current approach has proven to be stable, fast (10 Hz image acquisitions and processing) and precise (sub-micron resolution). Moreover, it is cost-effective and portable (it can be located very close to the equipment).

Epics Server: Future work

We plan to connect more than one camera to the same host card. The limiting factor here is the desired performance and data throughput. We also plan to use newer Linux kernel releases and IEEE1394 libraries that are intended to improve hardware detection and integration. The next goal is to be able to acquire and process the frames at the cameras maximum frame rate of 30 FPS.

HTTP SERVER

HTTP Server: Introduction

We developed a minimal HTTP server in order to be able to get an image from a camera (optionally compress it) without developing a dedicated client application. The purpose of the server is to allow direct camera access via any web browser or within an ad-hoc software. Also, the HTTP protocol offers many valuable features, for example: it is easy to implement, medium overhead, allow the transfer of large "documents" and of course allow using a lot of existing software.

Until Epics 3.14.x it was impossible to transfer in one shot more than 16 KB of data. With the aforementioned it is possible, but still not straightforward to transfer images if the size of the packet changes over time (for example when modifying the resolution, or while using the JPEG compression). HTTP allows circumventing these.

HTTP Server: Architecture

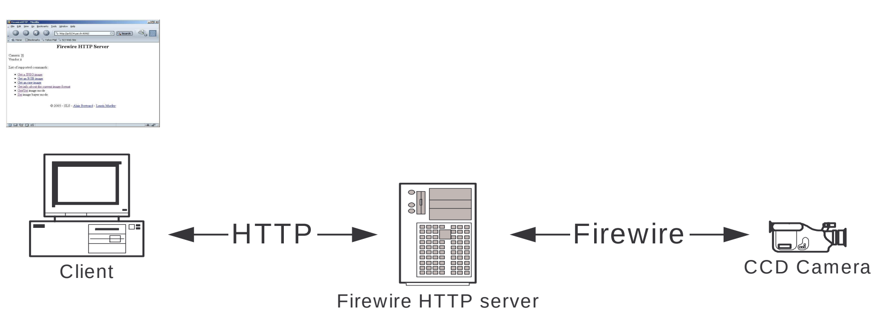


Fig 5 Firewire http server working schematic

Using the standard HTTP protocol, the client, for example a web browser, connects to the server. The server then interacts with the Firewire CCD using the Firewire Linux libraries. To prevent crashes of the server, a watchdog mechanism has been implemented, which recovers the server in case of problems.

HTTP Server: Supported commands

The main function of the HTTPD server is to retrieve JPEG, RGB or RAW images, obtain the current CCD status, get and set the current image mode, apply (if needed) the Bayer filter (color reconstruction) and depending of the CCD camera the server can also control the following parameters: Brightness, Exposure, Sharpness, Gamma, Shutter, Gain, Iris, Focus, Temperature, Zoom, Pan, Tilt, Quality, Filter.

CONCLUSIONS

The EPICS server approach allows for acquiring and processing the images at high rates (10 Hz). Thus, it can be used to track fast changes to the monitored system. On the other hand, it allows for online image processing to characterize synchrotron light and Laser beam. More importantly, it is fully integrated into the control system environment which has the obvious advantage of being operated simultaneously with other components in the beamlines or accelerator complex.

When this approach is used to transfer images to a client application, it suffers from a Channel Access protocol limitation. The protocol does not allow to resize dynamically (at run time) data blocks of waveforms (i.e. images). This implies that images, which are transferred from the EPICS server to the client application have a fixed size, and this, in turns, limits the use of image compressing algorithms.

The HTTP server approach is used to view the image and control some of the camera parameters. There is no image processing involved, and it is not interfaced to the control system. One advantage of HTTP server is that it offers the JPEG compression which significantly reduces the size of the transferred images.

These approaches are the outcome of different requirements from the beamlines, and so far, enabled scientists to do their work with the support for digital image acquisition and processing.

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