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DIGITAL CAMERAS FOR PHOTON DIAGNOSTICS AT THE ADVANCED PHOTON SOURCE*

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Abstract

Cameras can be a very useful accelerator diagnostic, particularly because an image of the beam distribution can be quickly interpreted by human operators, and increasingly can serve as an input to machine learning algorithms. We present an implementation of digital cameras for triggered photon diagnostics at the Advanced Photon Source using the areaDetector framework in the Experimental Physics and Industrial Controls System. Beam size measurements from the synchrotron light monitors in the Particle Accumulator Ring using the new architecture are presented.

INTRODUCTION

Measuring the beam size of the high brightness beams produced by the Advanced Photon Source Upgrade (APS-U) will be accomplished with cameras at various points in the acceleration cycle [1, 2]. The existing Advanced Photon Source (APS) has many cameras used to image the electron beam throughout the accelerator complex. Image output from most cameras is National Television System Committee (NTSC) analogue video, from which individual frames are acquired using a DataCube Max Video MV200 system [3,4]. In many other laboratories, digital cameras are used as part of the suite of accelerator diagnostics [5–9]. In anticipation of future capabilities for data acquisition and control of image data, potential need of a digital camera architecture is foreseen.

In the present work, we highlight recent work integrating digital camera control and data acquisition in the APS control system. Graphical and programmatic interface tools are outlined. A demonstration of digital camera use for the collection of beam physics data is presented.

SYSTEM ARCHITECTURE

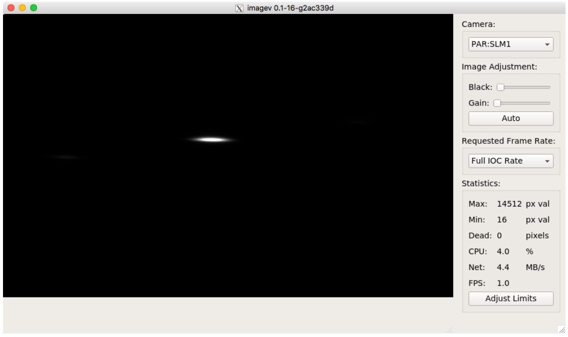
We have deployed several digital cameras. At present the cameras used are FLIR Point Grey Research Grasshopper3 USB3 cameras. USB3 was selected for these locations because the communication protocol supports high frame rate output. The cameras are directly connected to soft input output controllers (IOCs) running on local personal computers.

We use areaDetector to interface with the cameras [10,11]. The areaDetector package is used primarily as an Experimental Physics and Industrial Control System (EPICS) interface [12–15]. In addition, areaDetector modules provide initial data processing and analysis before publication as process variables.

For timing synchronisation, the cameras are externally triggered. For a variable delay, we use a digital delay generator (Stanford Research System DG645) triggered from the timing system injection event.

GRAPHICAL USER INTERFACE

A Python-based graphical user interface (GUI) has been developed. This makes use of the pvaPy Python module for PV access. An example image of the GUI is shown in Fig. 1.


imagev 0.1-16-g2ac339d

Camera: PAR:SLM1

Image Adjustment:

Black:

Gain:

Requested Frame Rate: Full IOC Rate

Statistics:

Max: 14512 px val
Min: 16 px val
Dead: 0 pixels
CPU: 4.0 %
Net: 4.4 MB/s
FPS: 1.0

Figure 1: Python graphical user interface for digital cameras controlled by areaDetector.

PROGRAMMATIC INTERFACE

For programmatic access to digital camera data, a Self-Describing Data Sets (SDDS) function was written called sddsimagemonitor [16, 17]. The function provides similar functionality to sddswmonitor, optimised for cameras controlled through areaDetector.

Using sddsimagemonitor we were able to acquire images using channel access protocol at a high throughput of about 100 frames per second when the region of interest was cropped to 128×128 pixels. This may be useful for specific time-resolved studies.

EXAMPLE OF USE

We have used this system successfully to image the electron beam in the Particle Accumulator Ring (PAR) [18] and in the Booster Synchrotron [19] of the APS accelerator complex. An example of the electron beam size measured using the PAR synchrotron light monitor is illustrated in Fig. 2.

One nice feature of the digital cameras is the 12-bit analogue to digital converter. This allowed the acquisition of all eight images in Fig. 2 on the same intensity scale, with-

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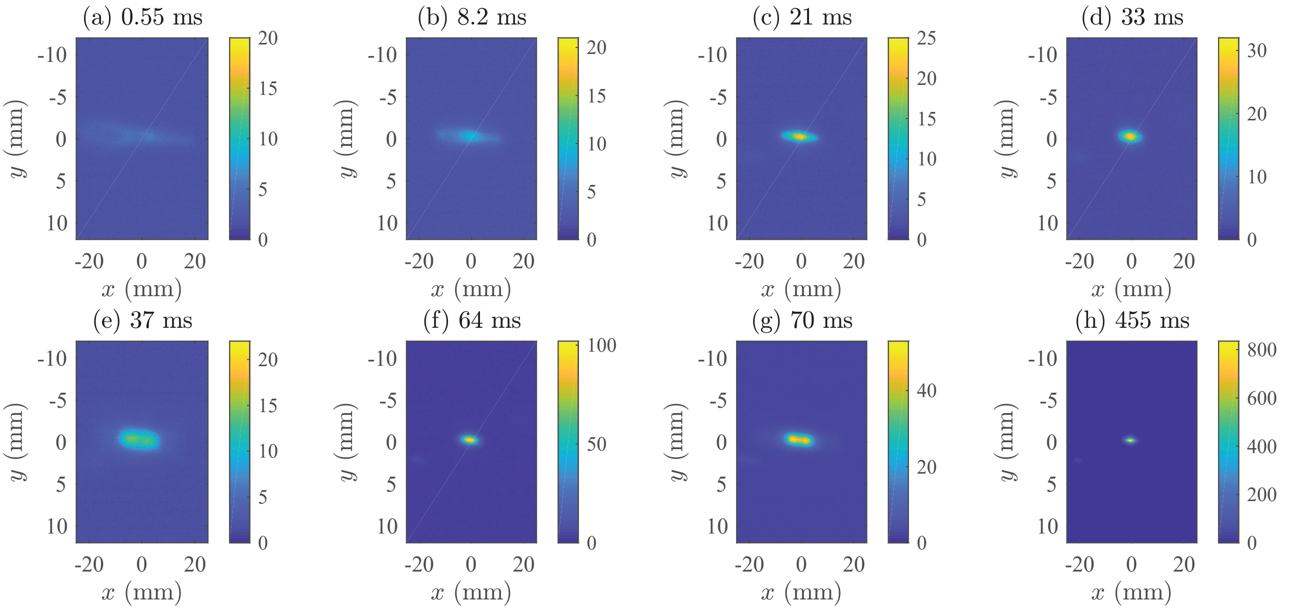

Figure 2: Transverse profiles of electron beam distribution acquired with digital camera at the PAR. (a) $t = 0.55$ ms. Immediately after the first injection of charge from the linac. (b) $t = 8.2$ ms. Damping of first injection of charge from the linac. (c) $t = 21$ ms. Damping of first injection of charge from the linac. (d) $t = 33$ ms. Just before the second injection, the beam distribution is damping. (e) $t = 37$ ms. Immediately after the second injection into the damping ring. (f) $t = 64$ ms. Immediately before the third injection into the damping ring. (g) $t = 70$ ms. Immediately after the third injection into the damping ring. (h) $t = 455$ ms. After several injections into the damping ring and the transverse emittance has damped to equilibrium.

out changing neutral density filters sensor exposure time, or gain.

The acquisition time of the camera was varied using the externally-delayed trigger. By varying this, we acquired a sequence of images at different times in the PAR injection cycle, to fit the damping time of the beam size. This is plotted in Fig. 3.

FUTURE WORK

Using USB3 cameras interfaced to local soft IOCs, we have demonstrated functionality of digital cameras for beam physics measurements that is not presently available with the existing suite of analogue video cameras. The next steps will be to prioritise particular imaging locations where the replacement of an analogue camera with a digital camera would provide immediate benefits to operations and physics analysis.

The present cameras have been implemented in locations outside of radiation enclosures where a local soft IOC can be positioned within a few metres of the camera itself. This allows the use of USB3 protocol for communications, which provides for short cable lengths of only ~5 m between powered signal repeaters. It is envisaged that several cameras may need to be positioned inside the accelerator enclosure. For those cameras, we envisage that GigE power over ethernet connections to cameras may be more appropriate. We are currently testing several cameras for suitability of this architecture.

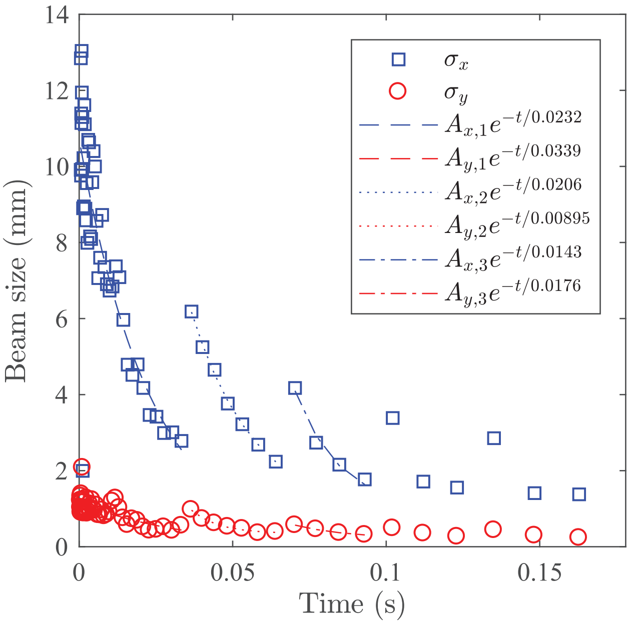

Figure 3: Measured electron beam RMS horizontal and vertical dimensions in the PAR damping ring. Successive injections into the PAR damping ring occur at 30 Hz (33.3 ms). The damping times in both the horizontal and vertical directions were fitted by fitting successive exponential distributions to the beam size with time after each injection.

CONCLUSION

We have demonstrated an implementation of digital cameras for control and data acquisition of the APS accelerators. Camera data acquisition and controlled are handled using areaDetector and EPICS. A demonstration of functionality provided by digital cameras in contrast to analogue cameras is given for the electron beam size transverse damping in the PAR damping ring.

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