IMPLEMENTATION OF IMPROVED INTERACTIVE IMAGE ANALYSIS AT THE ADVANCED PHOTON SOURCE (APS) LINAC

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Abstract

An image-analysis system, based on commercially available data visualization software (IDL [1]), allows convenient interaction with image data while still providing calculated beam parameters at a rate of up to 2 Hz. Image data are transferred from the IOC to the workstation via EPICS [2] channel access. A custom EPICS record was created in order to overcome the channel access limit of 16k bytes per array. The user can conveniently calibrate optical transition radiation (OTR) and fluorescent screens, capture background images, acquire and average a series of images, and specify several other filtering and viewing options. The images can be saved in either IDL format or APS-standard format (SDDS [3]), allowing for rapid postprocessing of image data by numerous other software tools.

1 INTRODUCTION

The Advanced Photon Source [4] linear accelerator system [5] consists of a 200-MeV, 2856-MHz S-band electron linac and a 2-radiation-length-thick tungsten target followed by a 450-MeV positron linac. The linac is designed to accelerate 30-ns-long pulses containing 50 nC of electrons to an energy of 200 MeV at 48 pulses per second. The 480-W beam is focused onto a tungsten target that serves as a positron converter. Positrons [and electrons] are re-accelerated from the target to 450 MeV.

The linac was recently outfitted with a thermionic rf gun [6]. A BNL-Gun IV photocathode rf gun [7] and glass drive laser will be added in the next few months, thus allowing the linac to become a free-electron laser (FEL) driver [8]. The ability to extract accurate, on-line measurements of important beam parameters from image data has become ever more important in view of the recent upgrades, thus the imaging system has been significantly improved over the past few months. Beam emittance, profiles, spot size, and spot shape are all valuable in tuning and debugging the linac and understanding its behavior.

The APS linac's original image analysis systems were based on high-performance pipelined image processing hardware (Datacube MV20/MV200 [9]) residing in a VME crate and controlled with EPICS software. The pipeline architecture of the Datacube modules allows for pixel manipulation while the image is being digitized and routed to image memory. Additional on-board hardware provides arithmetic operations and statistical analysis. These capabilities can be used to implement many image-processing algorithms, which can function at the full 30-Hz frame rate of the incoming video.

This advanced capability has a price. In addition to a sizable investment in hardware, extensive knowledge and training are required to properly configure, program, and test the pipelined hardware. All processing must be done in the VME environment, which requires a system reboot when new features or changes are implemented. The learning curve is substantial, thus many desirable features are never actually implemented.

Since the original image analysis system was implemented five years ago, significant increases in workstation and network performance have made it feasible to accomplish limited image analysis with a workstation-based tool. The advantages are:

- Able to use high-level software, such as IDL
- Easy to modify, enhance, and debug
- User-friendly access to file systems for saving, restoring, and manipulating data
- GUI interface
- Video-capture hardware knowledge is unnecessary

The disadvantage is that speed is compromised.

Table 1 lists benchmarks of some typical image analysis operations. These statistics demonstrate that if system requirements demand frame-by-frame processing, the only solution is an image processing system designed for that task. If, however, it is sufficient to perform the analysis at a 1-Hz rate, other options can be considered.

Table 1. Benchmarks of Some Typical Image Analysis Operations

	MVME 167	**Sun Ultra 2**	**Pentium 90MHz**	**MV200 512×480**
Proc. / **Function**	68040 - 25MHz	IDL	IDL	Image Processor
Backgr. Subtr.	146 ms	14 ms	55 ms	No O/head
Sum X	263 ms	24 ms	90 ms	2.3 ms
Sum Y	166 ms	10 ms	25 ms	2.3 ms

A workstation-based image analysis program that maximizes the capabilities of our hardware was developed and is currently in use at the APS linac. It was written in IDL (Interactive Data Language), a powerful

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4GL application development software package for data analysis and visualization.

2 SYSTEM OVERVIEW

The existing MaxVideo MV20 image processor is used to digitize the video image in the VME chassis. Through a new EPICS record type, an “image record,” the raw image data is made available to workstation-based clients via EPICS channel access. Since there is a 16-kbyte limit for each waveform in channel access, the image record presents the data as N scanlines of M pixels, where N is the vertical resolution of the camera and M is its horizontal resolution. For a typical camera of 480×512 pixels, the entire image can be fetched by retrieving 480 arrays of 512 bytes. This retrieval takes approximately 0.4 seconds on a typical 10-Mbit Ethernet network. A “smart” client will minimize retrieval time by only fetching the scanlines within a region of interest (ROI).

All other functionality is provided in an IDL application named “imageCatcher.” Standard EPICS provides a library such that channel access functions can be called directly from within the IDL code. The entire raw image can be fetched with the single IDL statement:

stat = caGet(pvNames, image, max=512, type=1)

where “pvNames” is a string array of the process variable (pv) names representing each scanline, and “image” is an IDL variable for a 2-dimensional array. The user-friendly “imageCatcher” main control screen is shown in Figure 1.

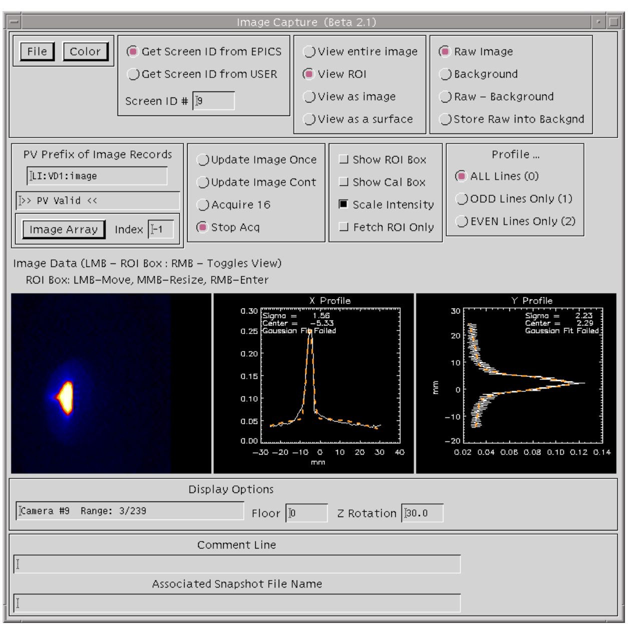

Figure 1: The “imageCatcher” main control screen. The user can easily select from several acquisition, calibration, and display options for any of the linac OTR, YAG, or Chromox screens.

The advanced IDL instruction set can easily be used to perform analysis functions on the IDL image data. Some features currently implemented in “imageCatcher” are:

- Background definition and subtraction
- Image display with pseudocolor surface view
- Surface intensity characterization with adjustable rotation and tilt
- Calculation and plotting of X and Y profiles
- Interactive screen calibration for conversion from pixels to mm
- Gaussian fit of profiles, with evaluation of fit quality
- Calculates position of peak intensity and sigma
- Performs online average of 16 consecutive images
- Saves image data in IDL or SDDS format for further analysis

The images can be saved in either IDL format or SDDS format, allowing for postprocessing of image data by other software. Figure 2 is an example of an “sddscontour” plot showing intensity versus position.

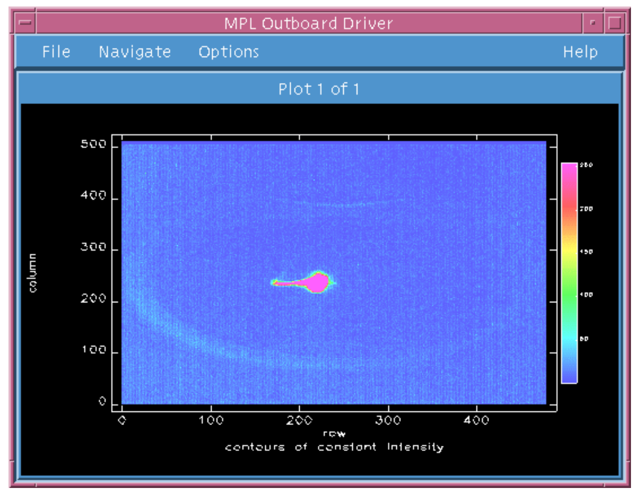

Figure 2: Contour plot of a thermionic rf gun beam spot on a Chromox screen obtained with “imageCatcher.”

3 APPLICATIONS

The APS linac is equipped with 10 Chromox fluorescent screens, 2 OTR screens, and 2 YAG crystals. These screens can be viewed with any of the standard CCD or CID cameras. Bunch length data can be obtained from the OTR screens by means of a streak camera. The Chromox screens and fiducials are at 45 degrees to the beam. The calibration procedure redefines the fiducial area to compensate for any angular dependence as well as for optical alignment errors. Many of the cameras allow the user to zoom, focus, and change the iris setting; therefore, the ability to rapidly establish a calibration before capturing the image is critical. “imageCatcher” allows rapid screen calibrations to be performed and to be associated with each measurement. The screen calibration utility is shown in Fig. 3. Beam emittance, profile, spot size, and spot shape are all extremely valuable in tuning the accelerator, debugging problems, carrying out accelerator studies, and generally understanding machine behavior.

Figure 3: "imageCatcher" calibration mode is shown. The solid box is the ROI and the dashed box is the calibration box. After drawing the calibration box, known coordinates of the four corners are entered at the bottom of the screen.

Transverse profiles at each screen can be compared to beam images on the same screen or on other screens from current and previous runs.

"imageCatcher" has been used to collect data for quadrupole-scan based emittance measurements and for the characterization of Chromox (Chromium doped Al_2O_3) screens. Figure 4 shows transverse beam size data from a quadrupole-scan emittance measurement using the DC thermionic gun. Image information was saved and later processed with SDDS tools.

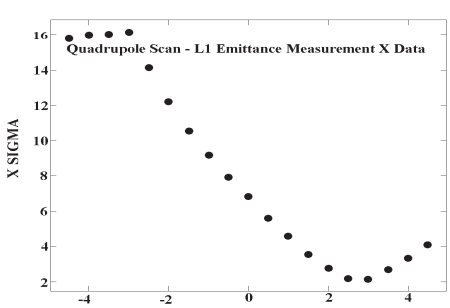

Figure 4: "imageCatcher" data; transverse beam size vs. quadrupole current, used to determine the emittance.

4 FUTURE PLANS

Future plans include upgrading the network to 100MBit, adding capability to correct the image for distortion due to the optics, and integrating "real time analysis" into the IOC so simple analysis can be done fast and more advanced analysis can be done on the workstation.

5 REFERENCES

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