IMAGE ACQUISITION AND ANALYSIS FOR BEAM DIAGNOSTICS APPLICATIONS OF THE TAIWAN PHOTON SOURCE

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Abstract

Design and implementation of image acquisition and analysis is in proceeding for the Taiwan Photon Source (TPS) diagnostic applications. The optical system contains screen, lens, and lighting system. A CCD camera with Gigabit Ethernet interface (GigE Vision) will be a standard image acquisition device. Image acquisition will be done on EPICS IOC via PV channel and analysis the properties by using Matlab tool to evaluate the beam profile (sigma), beam size position and tilt angle et al. The EPICS IOC integrated with Matlab as a data processing system is not only could be used in image analysis but also in many types of equipment data processing applications. Progress of the project will be summarized in this report.

INTRODUCTION

TPS (Taiwan Photo Source), a third generation 3 GeV synchrotron light facility, featuring ultra-high photon brightness with extremely low emittance which is being in construction at National Synchrotron Radiation Research Center (NSRRC) campus. It consists of a 150 MeV S-band linac, linac to booster transfer line (LTB), 0.15–3 GeV booster synchrotron, booster to storage ring transfer line (BTS), and 3 GeV storage ring.

For optimize machine operation and diagnostics applications, the two-dimensional (2D) beam profile images was used and recorded by cameras, which is widely used in synchrotron light source facility. The beam profile image has extensive information on beam parameters, including beam center, sigma, tilt angle and etc. The fluorescent screens convert the beam flux density as a function of position into a measurable signal, and charge coupled device (CCD) camera for image acquisition, were used in this application. Due to the most of machine parameters in future TPS [1] facility will be accessible as EPICS (Experimental Physics and Industrial Control System) process variables (PVs) [2]. Thus, an analysis tool use the PVs as inputs with ability to calculate and display results in complex ways is needed. In this moment, Matlab was chosen as the candidate computational tools, due to it offers a familiar environment and easy communicated with EPICS PVs. This report presents an EPICS integrated with Matlab as a data processing system which is not only could be used in image analysis but also in other equipments data processing. The hardware configuration and software structure will be summarized in this report.

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OVERVIEW OF INFRASTRUCTURE

This infrastructure is developed by using an EPICS IOC integrated with Matlab program to build up a data processing system. For the beam diagnostic application, this system is responsible for the beam profile acquisition from YAG:Ce screens, and used to analysis to find the beam characteristic data. The infrastructure employed can be divided into hardware and software components, as shown in Fig. 1.

Hardware Components

The hardware components include a computer, Gigabit switch, and cameras. The computer system based on EPICS 3.14.10 (Linux, 2.6.18) can act as a soft IOC (Input / Output Controller) which is used to communicate to cameras and collect images data via Ethernet. The Prosilica GC650 VGA-resolution CCD camera with GigE Vision is used which consists of 659×493 (Cell size 7.4 μm) light-sensitive pixels. The cameras have external trigger input port which can be used to receive trigger signal from timing system (EVG/EVR) for periodic data acquisition.

Software Components

The software components are constructed by EDM (Extensible Display Manager, 1.12.xx) and Matlab for cameras controlling and data analysing, respectively. The camera driver EPICS support is built by the areaDetector module [3] which provides a general-purpose interface for area (2-D) detectors at lower-level based on asynDriver [4]. The EDM was used to construct a client OPI for remote control the camera parameters. In this application there are two compiled Matlab programs were used; one is analysis program, the other is display GUI. The Matlab analysis program is continuously running inside the EPICS IOC's PC, through the Channel Access (CA, LabCA) [5] it can read the raw image data from the EPICS database, analyzed it, and then store the results back to the database records. The display Matlab GUI acts as client OPI which can show the analysis results in multiple clients simultaneously. All data are transmitted over the Ethernet network. In this study, Matlab provides a familiar environment and shows easy and efficient ways to reduce the development time and effort. The compiled Matlab programs help us to develop standalone Matlab application without running it in Matlab prompt which can save budget requirement of expensive licence fee. A Matlab runtime environment which is a free download needs to be installed, in order to execute the compiled Matlab program.
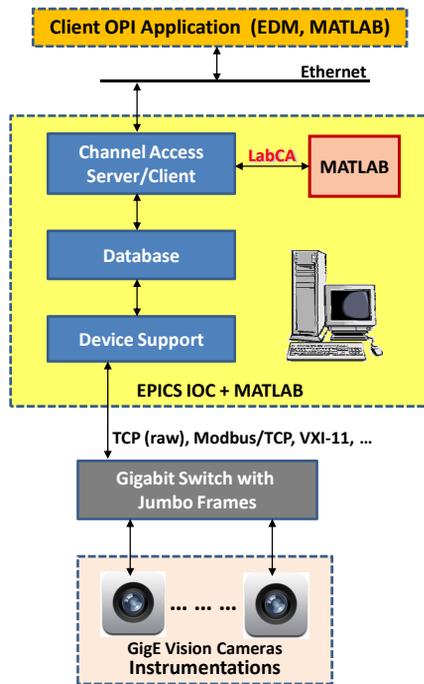
Figure 1: Overview of infrastructure.

FEATURES DEVELOPMENT

In this case, one EDM panel and two Matlab programs were created with difference functionality. The EDM panel which runs in client is used for controlling the camera parameters. The compiled Matlab programs, one is analysis program which runs as a background task in the of IOC's PC for image processing to online calculate the beam size, position and tilt angle; the other display GUI which runs in client for displaying the results and saving data. The detail program designs are shown as follows.

EDM Camera Control Panel (Client Side)

Based on the areaDetector module, using the EDM tool can easy construct a camera control panel as shown in Fig. 2. The camera parameters of exposure time and gain can be configured in this panel. The trigger mode selection include that the Free-Run is for simply monitor the image and Sync-In1 is for synchronization of linac injection (3 Hz). The *Show Image* button could pop-up a window to display the camera image. This EDM panel only offer control and simple monitoring features but do not perform any calculations.
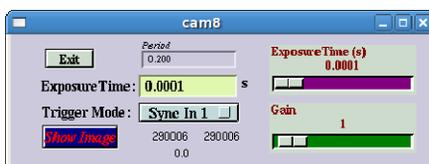

Figure 2: EDM camera control panel.

Matlab Analysis Program (EPICS IOC)

The Matlab analysis program runs in IOC's PC as a background task which can do a complex analytical work to analyze the beam parameters, including the beam center, sigma, and tilt angle. It can specify the region-of-interest (ROI) for clipping the image of each individual camera, and do an optional background subtraction and software multiple exposures. All the analyzed data will store into the EPICS IOC as PVs. The detail flow chart of the program is shown in Fig. 3. In the beginning, program will check which camera is active, then check the corresponding screen is ready or not. If not ready, the program will display some information, such as "No Camera Active" or "Screen is Not Ready". If pass the checking, the program will get raw image data (one-dimensional array) from the EPICS IOC, then go to the image process, including the reshape image array, RIO selection and projection process. Then, processing the image to find the beam center and tilt angle, and fit with a Gaussian distribution for sigma analysis. Finally, writing these results back into specific EPICS IOC PVs, then return to the START. The cycle time can be configured by timer in the program.

The least-squares curve fit, so called lsqcurvefit method was used to process the beam profile, which is one of the optimization toolbox in Matlab [6] which can solve nonlinear curve-fitting problems in the least-squares sense that minimized the sum of squared differences between the measured and predicted data, as shown by Equation (1). Lsqcurvefit is an iterative method which returns results that minimizes the residuals when the tolerances (TolX, default 1e-6) supplied are satisfied. That is, given input data *xdata*, and the observed output *ydata*, find coefficients *x* that "best-fit" the equation *F(x,xdata)*:

$$\min_{x} \frac{1}{2} \sum_{i} \left(F\left(x, xdata_{i}\right) - ydata_{i} \right)^{2} \qquad (1)$$

where *xdata* and *ydata* are vectors and *F(x,xdata)* is a vector valued function. This method can be used to deal with high signal-to-noise levels image.

There are others fitting algorithms can be used, such as the polyfit method, and the moment method. The polyfit method is a non-iterative method which can be used to solve linear problem with faster and accurate analysis, but in this case the data transformed (natural log) into a linear form is necessary. However, it can't deal with the Gaussian distributions with an offset condition, due to the mixed system with non-linear and linear components. The moment method is a computationally simple method to directly calculation the image parameters. For some applications such as image tracking, this method is common to use to analyze large data sets and computationally quicker but sacrifice precision. The three methods comparison for evaluation the computing time, fitting errors and noise tolerance had been described in previous study [7].
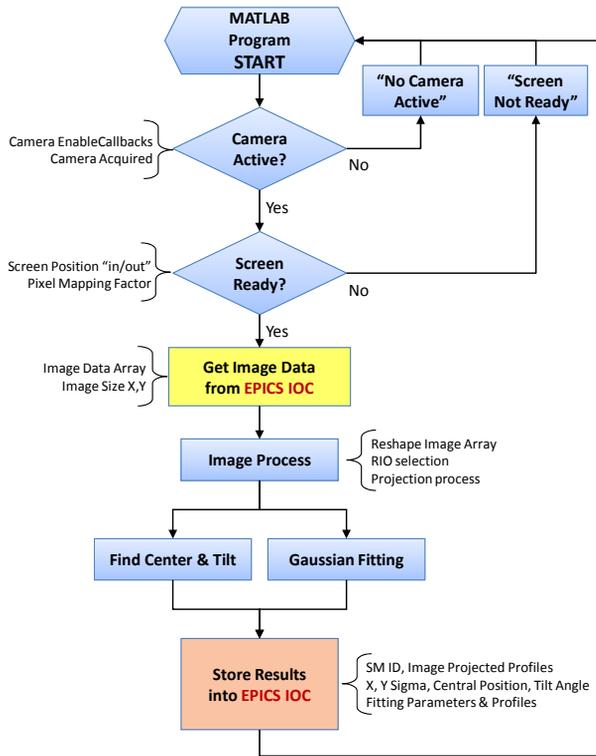
Figure 3: Flow chart of Matlab analysis program.

Figure 4: Layout of the Matlab display GUI.
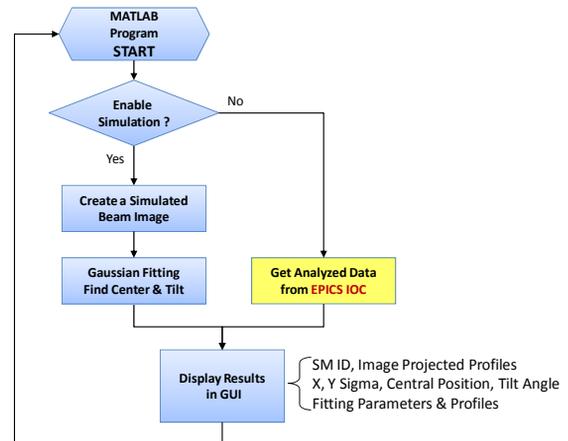
Figure 5: Flow chart of Matlab display GUI.

Matlab Display GUI (Client Side)

The layout of the Matlab display GUI is shown in Fig. 4. The GUI can run in multiple clients simultaneously and read the analysis results from EPICS IOC and display them in the window. The GUI contains six parts: menu, toolbar, control panel, fitting results, projected profile, and raw image. The menu and toolbar provide save data, colormap change, ROI specify, simulation, reset and close program, and zoom in/out functions. In the control panel it contains active the program, 3D viewing, multi-exposure, and background subtract functions. The fitting results area contains sigma and center in the units of pixel and mm, and beam tilt angle. Two directions, horizontal and vertical, of beam projected profiles of raw data and fitting curve are predrilled in two axes. The camera raw image with the colorbar is integrated into the display GUI. The function of export the raw image data and analysis results can be done. It also can create a simulated beam image for the purpose of evaluating the fitting correctness.

The detail flow chart of the program is shown in Fig. 5. In the beginning of the program, users can *Enable* or *Disable* the simulation option. If enable the simulation, the program will generate a simulated beam image then go to analysis process as previous. If disable the simulation, the program will get the analyzed data from EPICS IOC and display the results in the GUI, then return to the START. The cycle time can be configured by timer in the program.
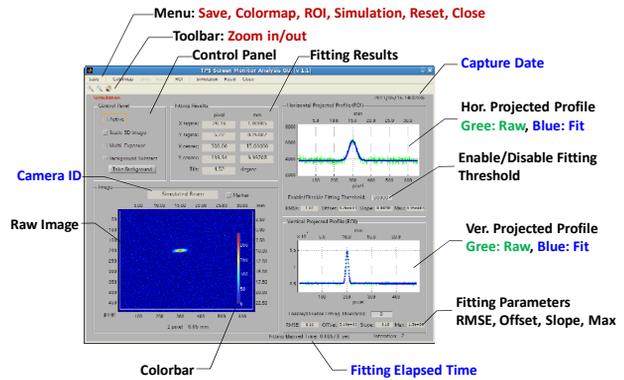
IMPLEMENTATION IN TPS LINAC

The beam profile of the TPS 150 MeV linac is measured by five YAG:Ce screens [8]. The screen is mounted at 45° against beam direction and driven by a pneumatic driver. The fluorescence light goes out in horizontal direction. The optics consist a refraction mirror bend the light 90° to the 75 mm lens and camera. The resolution of this configuration is ~60 μm/pixel, which is acceptable for TPS current beam size of ~0.5 mm order. The typical layout of the screen monitor is shown in Fig. 6(a). Screen monitor of the test transport line at early commissioning stage is 25 mm diameter YAG:Ce screen with 0.5 mm thickness. This screen is mounted at a manual driven mechanism. This provision solution will be used at early stage of the beam test due to tightly schedule. The typical layout of the screen monitor is shown in Fig. 6(b). The real beam profile, which on the after of gun, was analysis as shown in Fig. 7. The sigma of beam size is in sub-mm order, and tilt angle is also shown in the GUI. The unusual diffraction at position of [X=200 pixel, Y=200~300 pixel] is probably a reflection due to the edge of the YAG:Ce crystal disk. Fortunately, it can be easily ignored by the ROI function. All fitted parameters will be stored as EPICS PVs such that clients can easily access it for further usage.

Figure 6: The configuration of screen monitor at (a) linac and (b) test transport line.
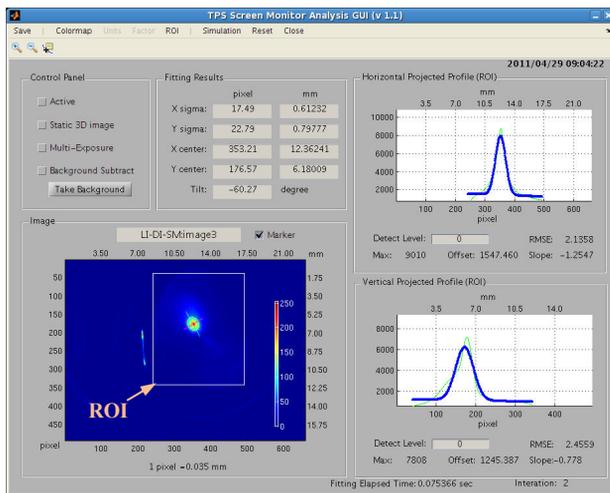

Figure 7: Screen monitor analysis GUI for real beam profile.

Table 1: Timing of the Analysis Program

Process	Time Required (ms)
Read/Write data from PVs	< 30
Data process	< 80
Total	< 110

FUTURE DEVELOPMENT

Using EPICS IOC integrated with Matlab as a data processing system is a simple way to develop an application quickly. This solution can be extended to other applications, such as beam lifetime calculation, filling pattern measurement, real-time oscilloscope waveform analysis, synchrotron radiation monitor image analysis, and other equipments data processing. Waveform analysis will be very useful to monitoring the pulse system functionality and stability likes linac microwave system, and pulse magnets system (septa and kickers).

SUMMARY

In this report, we used Matlab to assist EPICS IOC to improve its calculation ability, which will become an alternative solution for complex data analysis. Benefit of this approach can meet expertise of available manpower and more productivity. Compile version of Matlab scripts save budget requirement of expensive licence fee. There are various feature of software have been described here. This infrastructure has been implemented and regularly used on screen monitor image analysis for TPS linac diagnostics application. From timing point of view, there would be no problem running the application on TPS, due to TPS injector repetition rate is 3 Hz. Further studies of other applications of this solution are currently ongoing.

TIMING EVALUATION

A timing evaluation of the analysis program was made and summarised in Table 1. The specifications of computer in the experiment for preliminary test are as follows: Intel Xeon 2.26 GHz CPU, 4.0 GB DDR3-1333 RAM. There are two key processes can affect the time required for each image frame. One is read/write data from PVs via EPICS channel access, and the other is fitting projected profiles. The read/write data from PVs, including some conditions and raw image data array, take less than 30 ms. The data process, including two times of fitting process (horizontal and vertical) and tile angle recognition, takes less than 80 ms. Thus, the program requires less than 110 ms per each cycle, which means the maxima processing rate can be up to 9 Hz. This performance is the worst case due to the computer has other tasks to handle at the same time, but this result still acceptable for TPS 3 Hz facility. In future the repetition rate can expect up to 10 Hz rate or higher rate by using a dedicated computer which would be beneficial for many applications.

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