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NEW ALL-DIGITAL CAMERA SETUP AT THE KARLSRUHE RESEARCH ACCELERATOR

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Abstract

Until recently, the Karlsruhe Research Accelerator (KARA) located at the Karlsruhe Institute of Technology (KIT) was using analog cameras to monitor fluorescence screens. By now, all cameras have been replaced by digital cameras directly connected via Ethernet, making it possible to directly integrate them into our EPICS-based control system. The new control system integration also provides for a better continuous statistical analysis and comparability of camera pictures. This paper presents an overview of the new setup, including the post-processing integration making use of Python.

INTRODUCTION

KArlsruhe Research Accelerator (KARA) provides a 2.5 GeV storage ring and light source for experiments with electron beams and synchrotron radiation. The storage ring saw its first beam in 2001. Over time, a comprehensive refurbishment program has been carried out. An important decision was to migrate to the EPICS control system [1], which started around 2012. Replacement of the main power supplies completed this process after 12 years [2, 3]. The original, analog cameras were one of the last parts to be replaced, whereas in-between different setups with framegrabber and video-switching systems were in use.

TECHNICAL SETUP

The requirements for the digital cameras were to use the GigE Vision protocol and, ideally, power-over-ethernet (PoE). We decided to use a rather inexpensive monochromatic camera with up to 25 FPS from Basler, the acA1920-25gm, as the default camera of choice. This reduced the technical integration effort down to designing a new mechanical holder for the camera casing, as well as connecting the cameras via Ethernet to our existing network infrastructure. In addition, a trigger cable is distributed to most cameras and connected to our overall timing system. While this camera model fulfills the basic requirements for the applications at KARA, we can also make use of higher-performance camera models, if needed, with minimal effort. Nevertheless, the chosen model already increases the resolution by nearly a factor of 10 to 0.02 mm/pixel and provides 12 bit resolution.

Electron Beam Screens

At KARA, there are two different setups that use cameras. One is fluorescence screens (FS) that can be moved into the electron beam path pneumatically. As this will fully absorb the beam, only one of these cameras will ever be used at the same time. From a required processing power perspective this leaves the main factor being the 1 Hz injection rate of the KARA injector, as FS cameras will operate with this as the trigger source. These screens were mostly used for basic commissioning, inspecting individual screen positions qualitatively compared to a reference beam position. Due to the position of the screens along the path of injection, the beam shape is rather unique — and sometimes quite far from round — for most locations. With the digital cameras now providing more accessible, higher resolution, and already pre-analyzed data for further quantitative analysis, new applications for machine learning-based optimization making use of beam screens are currently in development [4].

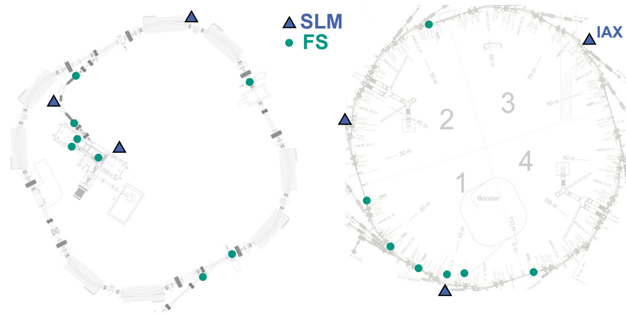

Figure 1: Overview of cameras positions. Left shows the injector and right the storage ring. The red dots indicate FS screens (15), while the green triangle represents SLM setups (6).

Synchrotron Light Measurements

The second setup makes use of synchrotron light that is emitted by the electron beam while being deflected. The synchrotron light is guided by optical mirrors to a camera, avoiding higher intensity x-ray sections of the radiation. As these so-called synchrotron light monitors (SLM) do not influence the source electron beam in any way, all SLM cameras can be used at the same time. The SLM setups (as shown in Fig. 1) along the injector will, of course, only show light during the injection process, whereas the SLM in the storage ring itself can be used to continuously monitor beam shape and position on the camera during injection, the energy ramp, and the normal beam operation.

In-Air X-Ray Detection

KARA also uses an in-air X-ray setup [5], where the X-rays travel through a crotch absorber and a scintillator before

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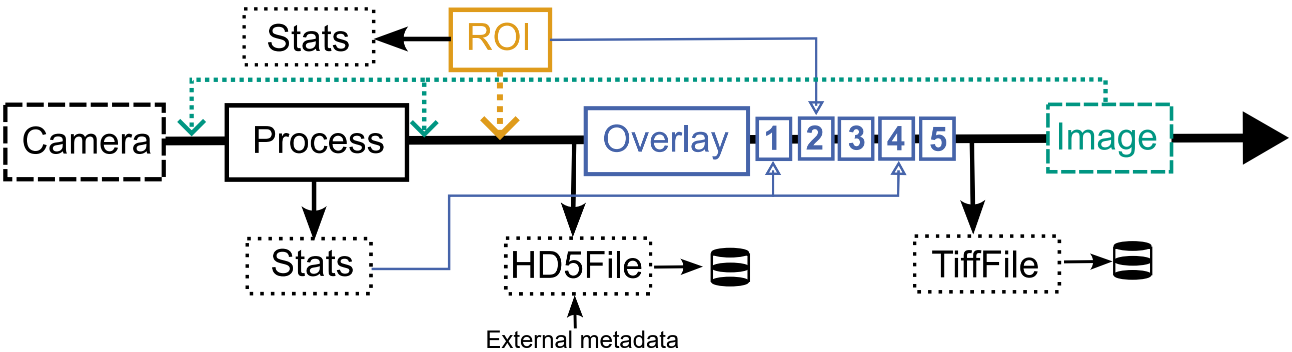

Figure 2: Plugin setup of areaDetector showing the main processing path. Elements with a solid border represent plugins which create a modified output of the source data, while the elements with dotted borders only use the source as input to provide data. The process plugin takes mostly care of background subtraction and the stats plugin provides profile and centroid information. The ROI plugin can be moved into the processing path on demand. The overlays adds optional elements to the image such as centroid position and timestamp. The HDF5 export is designed for offline analysis of the images and therefore is always taken before any overlays are added.

being imaged by a camera. While this setup can only be used at high enough beam energies (>2.1 GeV), it allows for precise measurement of the vertical beam size.

CONTROL SYSTEM INTEGRATION

The cameras are integrated into the EPICS control system by using the *areaDetector* module [6]. The Basler cameras are integrated using the *ADGenICam* driver, which allows to leverage the GigE protocol to configure and make available camera-specific features, and automatically generate the necessary EPICS records and graphical user interfaces. areaDetector allows running multiple cameras in one server application (*input output controller (IOC)*). Running multiple cameras in one IOC has the advantage that plugins can be shared, as the location of the camera output, as well as all plugin input sources and output locations, can be dynamically adjusted during runtime. Moreover, because most cameras will never run at the same time, distributing the cameras to reduce the load of individual IOCs is not necessary.

Plugin Configuration

areaDetector comes with many optional plugins, which can be configured. As these plugins provide a standardized in- or output, they can be chained in many different ways. The default configuration of plugins we provide for most cameras can be seen in Fig. 2. The raw camera picture is first passed through the *process* plugin, which we mostly use for optional background subtraction. After that we make use of the stats plugin, which we use for centroid detection and horizontal and vertical beam profiles calculation. At this point a region-of-interest (ROI) plugin can be used, followed by another stats plugin only looking at the selected ROI.

The processed and analyzed picture can then be stored via the HDF5 plugin with additional metadata to file, either as a single shot or multiple captures. After the HDF5 plugin the overlay plugin is configured to provide helpful graphical information to the operators, such as the current centroid position, the defined ROI, label and timestamp and the cursor position for manual profile calculations. These overlays can be switched on and off by the operator. The image which is presented in our GUI is the final output of the overlay plugin and the final plugin is a tiff file plugin to export snapshots with or without labels.

If the ROI plugin shall be used, the plugin chain starting from the HDF5 export can be adjusted to take only the selected ROI into account. The operator may also choose to adjust the source of the actual image presented in the GUI to show the raw camera image or the image directly after the processing plugin. There are even more plugins which might be integrated - if required - at a later point in time, such as circular buffer or compression plugins.

Panel Integration

With the plugin configuration described above, each camera has around 800 parameters and configuration options. It is therefore important to curate the panels to show only the most relevant options for the different use-cases. Figure 3 shows the basic view for an operator, while increasingly more complex configuration panels for plugins and camera settings have been implemented for experts to use.

Post-Processing

While the areaDetector plugins cover most generic processing needs in most likely the most efficient option, certain measurement routines and experiments require additional post-processing. One such use-case is the determination of the actual beam-size based on the SLM centroid, as this requires additional external input. For one of the SLM setups, it is possible to insert a double slit. The resulting interferogram improves the resolution when determining the vertical beam size [7]. For this, we leverage Python scripts and Python IOC integrations using Python SoftIOC [8].

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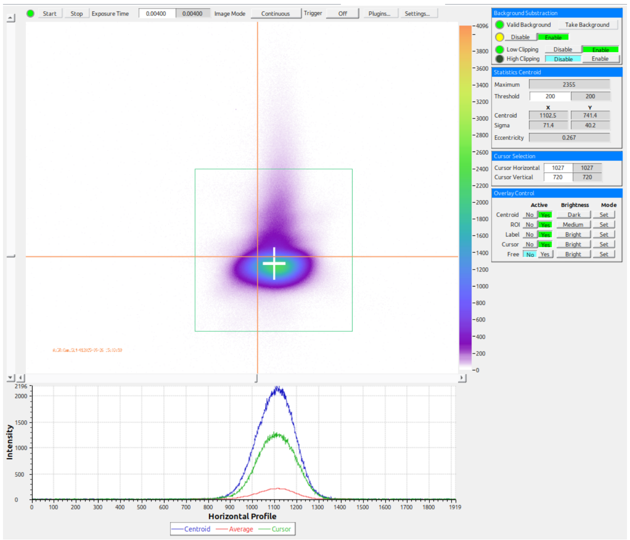

Figure 3: Operator panel. The basic control is on the top with profiles on the bottom. The image, after post-processing as discussed in Fig. 2, takes the center area, with the active overlays shown: centroid, ROI, label and cursors. Plugin control is on the right: Overlays can be switched on or off, the overlay brightness can be adjusted, background subtraction can be enabled, as well as control for the statistics module. The cursors can also be adjusted there, but also by dragging the scroll-bars next to the image.

CAMERA MANAGEMENT

With thousands of configuration parameters across all plugins, cameras, and IOCs, managing the overall setup is critical. We split the management into three categories.

Operator Management

The operators have basic control and overview over the cameras: which cameras are active, the option to manually start and stop acquisition and access to a basic set of parameters, such as the exposure time and the external trigger choice. For the most important parameters, panels have been implemented to provide an overview of all cameras, as well as quickly adjust some of the settings. As part of the operator management, certain parameters have been included into the alarm system to notify the operator in case of issues.

IOC Management

The IOC takes care of the distribution of cameras to IOC instances, as well as the initial configuration of all plugins and their settings. After the initial setup, the EPICS *autosave* module [9] is used to store all parameters persistently across IOC restarts. The IOC running the FS cameras alone tracks around 12.000 parameters.

Script Management

The IOC takes care of the initial configuration. But once a camera setup is online, choices made by the operator will store those values via autosave, effectively overwriting any defaults set in the start up file. To still be able to set defaults or change values globally, we designed a management script using a custom YAML configuration file for the overall camera management.

The configuration file provides a default base configuration, only defining options which should be forced on the camera configuration. It then allows to re-define the same or add new options to a subset of cameras, either FS or SLM types. One example is the external trigger option: The SLM cameras typically run without trigger, while the FS cameras should be set up with an external trigger source. If desired, parameters can also be defined on an individual camera level. A set of variables can be used, which will be replaced dynamically before being written onto the IOC. One example is the file path for storing images via the file plugins. This file path consists of a generic file path as well as a folder based on each camera.

The script also provides options to show only differences in the pre-defined configuration or to apply any change only to a subset or even individual cameras. This becomes especially useful if the overall plugin configuration needs to be adjusted. While the script is currently used by the system expert, an integration into the operator panels is under consideration to display wether differences have been found and the option to revert to default settings.

OUTLOOK

The next steps involve fine tuning the plugin configurations, as well as extending the same setup to our other accelerators. This includes improving the panels to provide the operators with easy and direct access to the relevant parameters for adjusting the camera picture to the current beam situation, while the underlying detailed setup is handled by the management script. Another focus lies on a certain level of automation, such as the automatic starting and stopping of data acquisition based on the position of the screen or the status of the accelerator. There are ideas to further optimize the management script in order to offer increased flexibility in defining the camera configurations as well as rolling out the settings. For example, only applying the configuration for one particular plugin could be useful. Finally, the new digital camera setup can now be integrated into various measurement routines, which might require additional post-processing in Python.

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