

PROFILEVIEW - A DATA ACQUISITION SYSTEM FOR BEAM INDUCED FLUORESCENCE MONITORS*

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Abstract

Along the GSI linear accelerator, several Beam Induced Fluorescence (BIF) monitors are installed. Due to the non beam-intercepting measurement principle, multiple BIF monitors can be active simultaneously to observe the beam at different locations. For this novel possibility, the software called ProfileView has been developed, allowing users to view beam profiles coming from several BIF monitors. This contribution describes the different hardware devices of the GSI BIF monitor installation and the according software to control these devices.

MOTIVATION

Beam Induced Fluorescence monitors determine the transversal beam profiles without beam disturbance [1]. Therefore, they are well suited to observe the beam at several positions in the accelerator at the same time. Presently, two BIF monitors are installed in the GSI linear accelerator. In the next two years, a final number of seven BIF monitors will be installed to observe the beam throughout the linear accelerator and in the transfer line to the synchrotron. The readout of the two image intensified cameras of a BIF monitor has formerly been realised with outdated LabView programs. Just one camera could be monitored at a time, so horizontal and vertical profiles had to be measured successively. The new software called ProfileView overcomes these limitations and allows machine operators to view multiple BIF monitors at the same time through an easy-to-use graphical user interface (GUI) which can be seen in Fig. 1. Up to three different BIF monitors can be observed and compared at once. By default, the pressure is the only parameter to tweak the signal strength. For advanced users, every parameter of the system can be fine-tuned in a password protected 'Expert mode'.

HARDWARE

The hardware of the BIF system is in wide parts similar to the hardware of the BeamView system for scintillator screens [2]. Each BIF monitor consists out of the following hardware components depicted in Fig. 2:

- two FireWire cameras (for the horizontal and the vertical profile) with multi-channel plates (MCPs) for image intensification and remote-controllable irises
- a National Instruments Compact Vision System (CVS) [3] or standard PC for camera readout and digital image processing

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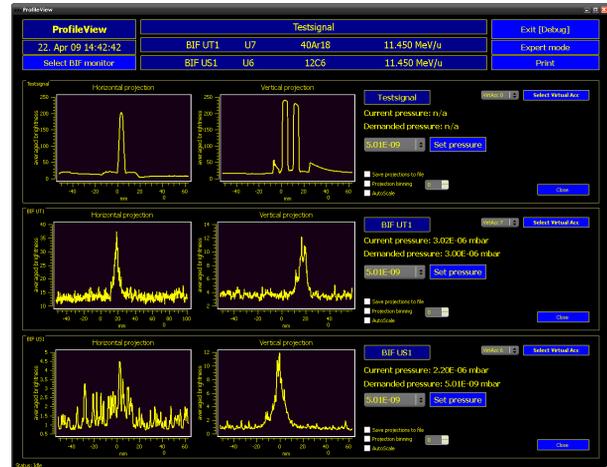


Figure 1: ProfileView graphical user interface.

- Ethernet connected DAC electronics for iris and MCP amplification control
- pressure control unit to inject defined gas pressures into the beam pipe
- timing decoder to trigger the cameras and the image intensifiers
- remote controllable power plugs to reset system components
- a computer running ProfileView to display images and projections and control all hardware devices

Image Acquisition System

To acquire images, standard FireWire cameras (Basler A311f) have been equipped with custom made image intensifiers (Proxitronic) for single photon detection. The cameras are connected to dedicated image processing hardware, acting as middle layer between the camera and the computer running the GUI. For this purpose, an embedded system (National Instruments Compact Vision System 1456 [3]) can be used. This embedded computer is equipped with FireWire interfaces, an FPGA with digital I/Os, network connectivity, a 733 MHz CPU, 128MB RAM and 256MB non-volatile storage. The CVS is capable to control up to 16 cameras connected via FireWire hubs, with four of them running simultaneously. It is programmed via LabView Realtime, FPGA and Vision packages. It is also possible to use a standard Windows PC with FireWire ports and an FPGA card instead of the CVS to achieve higher system performance. Besides some minor adaptations, the software for the CVS and the PC is the same.

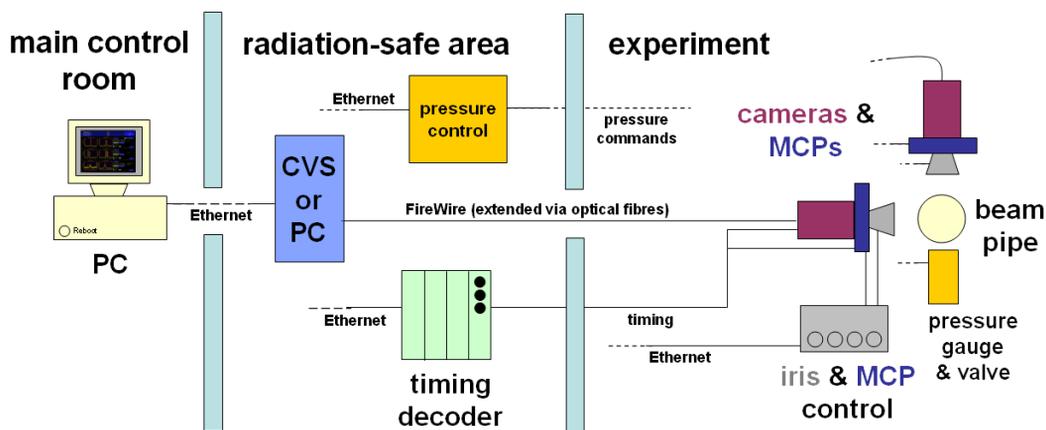


Figure 2: Schematic of the BIF monitor hardware.

Supplemental Hardware

Every device in the BIF system is controlled via Ethernet. To trigger the cameras and the MCPs with respect to the beam pulse, a programmable timing interface is used. The camera iris and the MCP amplification are controlled by a simple DAC electronics. A commercial pressure control unit (Pfeiffer RVC300) creates the pressure bump inside the beam pipe for gas excitation. The typical pressure range for BIF operation is between 10^{-7} and 10^{-5} mbar, using nitrogen as working gas. For remote reset capabilities, all devices are connected to remote controllable power plugs. In case of malfunction, each device can be reset separately. To minimize radiation damage, most of the active electronics is placed outside the accelerator tunnel.

SOFTWARE

The software of the whole BIF system is split into two parts: The image acquisition software is written in LabView and running on the CVS (or PC). The other part called ProfileView is written in C++, displays images and controls all system devices. The CVS and ProfileView communicate with each other via standard Ethernet.

Software on the CVS

The part of the software running on the CVS is responsible for acquiring images and performing calculations on the image data like the computation of projections or histograms. This data is sent across the network to the PC running ProfileView. A specification of the requirements for the CVS software has been created and given to an external company which developed the LabView application and a C++ application programming interface (API) for ProfileView [4]. It has been implemented to serve both use cases, scintillator screens and BIF monitors. The CVS software offers the following features:

- control up to four cameras simultaneously
- calculate histograms and projections of the incoming images

- buffer data in case of heavy network traffic or unavailability of the client
- disable triggers in the FPGA in case the camera is busy processing the last frame
- send the results via Ethernet
- XML interface for CVS and camera control

The functionality is realized with independent image acquisition threads, each controlling one active camera. The default behaviour is sending of projections only (without the original images) to save network bandwidth. If the user wants to observe and save the original images too, it can be enabled in the Expert Mode. The typical bandwidth of uncompressed images with 5 Hz is around 24 MBit/s per BIF monitor. The system is controlled by human readable XML commands, sent over the same socket connection as all other data. To deliver images, processed data and command responses, an application layer protocol is used to distinguish between XML and binary data. The API allows easy access to the arriving data and command submission. Communication takes place over standard Ethernet sockets using the TCP/IP protocol. Since Ethernet is a non-deterministic technology, buffers are implemented on the CVS. When there is heavy network traffic or the client is not ready to receive data, the CVS stores all data in a configurable ring buffer. The submission is continued as soon as the network is not overloaded any more or the client acknowledges the reception of the last data package.

ProfileView

The software part called ProfileView is responsible to receive data from one or more CVS systems and to control all supplemental hardware devices. To understand the interaction of the different classes, a typical startup of a BIF monitor and the following data flow is described:

As soon as a detector is selected in ProfileView, the startup sequence initializes the horizontal and vertical camera of the BIF monitor. The startup procedure sets camera specific attributes, e.g. integration time, gain or video mode. When the cameras are initialized and waiting for

triggers, the CVS is informed to calculate projections of the images arriving in the future and to forward them to the computer running ProfileView.

After camera initialisation, the value for the demanded pressure is sent to the pressure hardware. The pressure control class is implemented as a separate thread, which requests the current pressure in the beam pipe every three seconds. When the user wants to set a pressure, the new value is sent to the hardware and the valve opens to adjust the new pressure accordingly. To avoid flooding the accelerator with atmospheric pressure, only predefined values can be set. An arbitrary value can be entered in the password protected ‘Expert Mode’.

A network connection is established to the DAC electronics controlling the camera iris and the MCP. For reasons of hardware protection, the connection has to remain open and the demanded values have to be sent every few seconds. In case of an unexpected disconnection, the hardware closes the iris and shuts down the amplification voltage. This way the MCPs will be left in a safe state in case of a network or software error. For reliability and safety reasons, the GSI-built DAC electronics will be replaced by a commercial programmable logic controller in the future.

Finally the timing hardware is initialized. As soon as the desired event occurs on the GSI timing bus, the timing hardware sends a trigger to the camera to start acquisition of an image and a gate to activate the MCPs.

Once an image arrives at the CVS over the FireWire bus, the projections are calculated and stored in a buffer. A ‘network sender’ thread takes the oldest buffer element and sends it to the computer running ProfileView. Projections, histograms and images are transferred as binary data, error messages and commands as XML strings.

The complete programming of ProfileView is done in C++ using the Qt framework [5] for platform independent GUI, thread, network and XML functionality. For data processing, extensive use of the Qt signal/slot mechanism is made. When data has been read from the network, a Qt signal, comparable to an interrupt, is raised, with a pointer to the new data as an argument. The GUI layer receives this signal and updates itself with the new data. To avoid read/write concurrency issues, memory locking and acknowledge mechanisms have been implemented. Each hardware device is represented as separate Qt class. A class called `gsiBifMonitor` combines all device classes into a virtual representation of the physical hardware setup.

USER EXPERIENCE

Typical frame rates in operation are between 5 and 10 Hz. The maximal achievable frame rate of the system depends on the hardware and the data rate (see Table 1). If just the projections are sent to the client, the frame rate is between 50 and 66 frames per second (fps). If the original images of one or both cameras are requested additionally, the maximal frame rate drops considerably and a PC should be used. The data rate of a BIF monitor trig-

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Table 1: CVS vs. PC Performance Comparison

Requested data	CVS	3 GHz PC
projections only	~50fps	~66fps
proj. with one image stream	~14fps	~52fps
proj. with two image streams	~8,33fps	~37fps

ged with 20 Hz grows from 0.8 MBit/s (projections only) over 50 MBit/s (projections and one image stream) to ~110 MBit/s when both original images are requested. The CVS systems are used for historical reasons, easy system setup and their reliability in operation due to the real-time operating system and the robust hardware. A Windows PC is faster and cheaper, but the non-deterministic operating system can cause an error in very rare occasions.

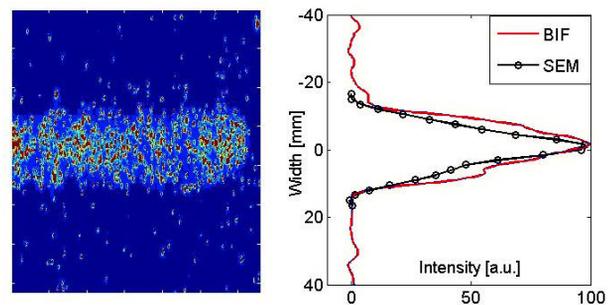


Figure 3: Comparison between a false-color image of BIF and a secondary electron emission grid (SEM).

The results of BIF measurements show the functionality of the measurement principle for different ions in the energy range from 1.4 to 750 MeV/u [1]. For lower energies, secondary electron emission grids (SEM) are the standard diagnostic device at GSI. To validate the measurements of the BIF monitors, data of both systems has been compared. The profiles (average of 5 beam pulses) of a high current (4.5 mA) Ar^{1+} beam with 1.4 MeV/u show good agreement in width and shape between BIF monitors and SEM grids (see Fig. 3 [6]).

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