Development of the beam diagnostic system of the HUST-PTF transport lines

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Abstract

Huazhong University of Science and Technology is building a cyclotron-based proton therapy facility (HUST-PTF). The facility mainly consists of a 240MeV superconducting cyclotron, a beam transport line, a fixed treatment room and two rotational treatment rooms. HUST-PTF uses three kinds of detectors, Scintillation, Faraday cup and ionization chamber, for the beam property measurements. In terms of structure, the HUST-PTF beam diagnostic system is built according to the standard distributed three-layer structure, which is divided into hardware device layer, data processing layer and GUI layer. Different protocols are used to communicate between the three layers, which can improve reliability and expand flexibly in each layer.

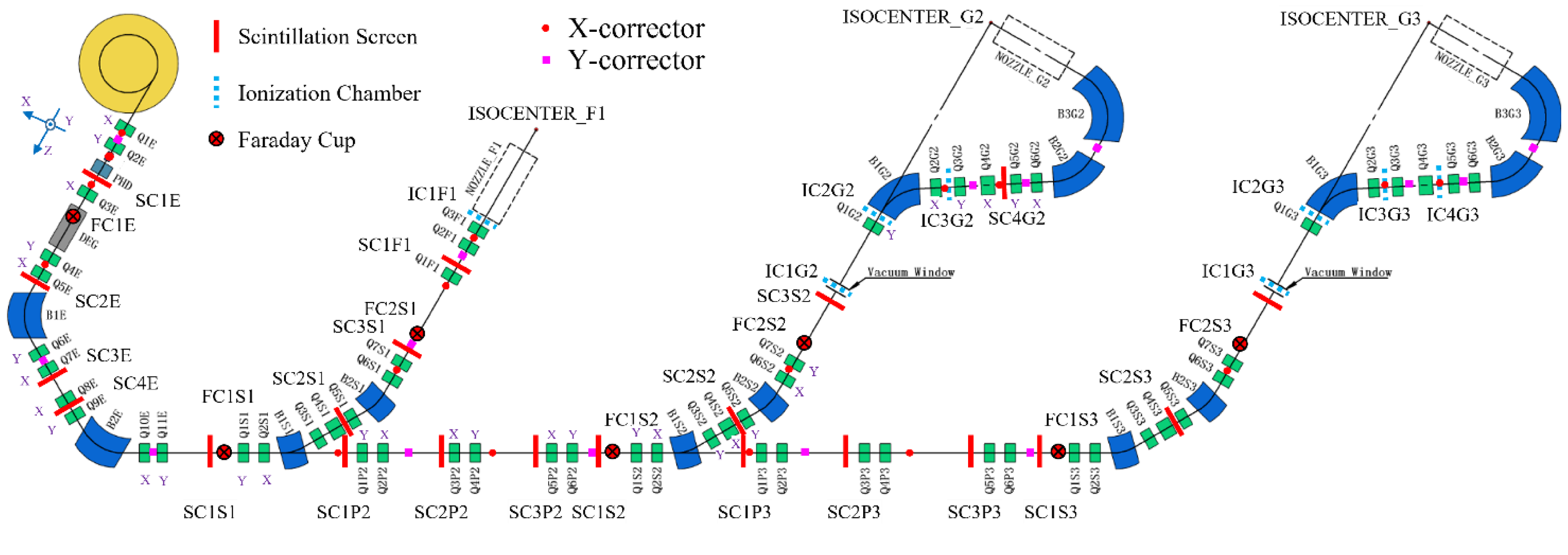

Fig. 1 Beam direction and overall layout of HUST-PTF beamline. The label of each detector is explained as follows. explained as follows. The first two characters indicate the type of each detector. SC: scintillation screen; FC: Faraday cup; IC: ionization chamber. The last one or two characters indicate the location of each detector. E: energy selection section; S1, S2, S3: switch sections; P2, P3: period sections; F1: fixed-beamline room; G2, G3: gantry-beamline rooms.

HUST-PTF beam diagnostic system architecture

In terms of its overall architecture, the HUST-PTF beam diagnostic control system adopts the standard distributed system architecture, with the overall structure divided into three layers: the hardware equipment layer, the data processing layer, and the GUI layer.

The hardware equipment primarily consists of beam detectors, pneumatic devices, and high-voltage modules, which can collect beam information and convert it into the corresponding analog signal. The data processing mainly encompasses the controller of the front-end detector, I/O modules, motion controllers, etc., which primarily achieve the digitization of beam properties, transmit the measured and calculated data to the upper control system, and facilitate data exchange between the front-end detector and the user interface. In the GUI layer, the operator can control the motion of the detectors and the detection of beam parameters.

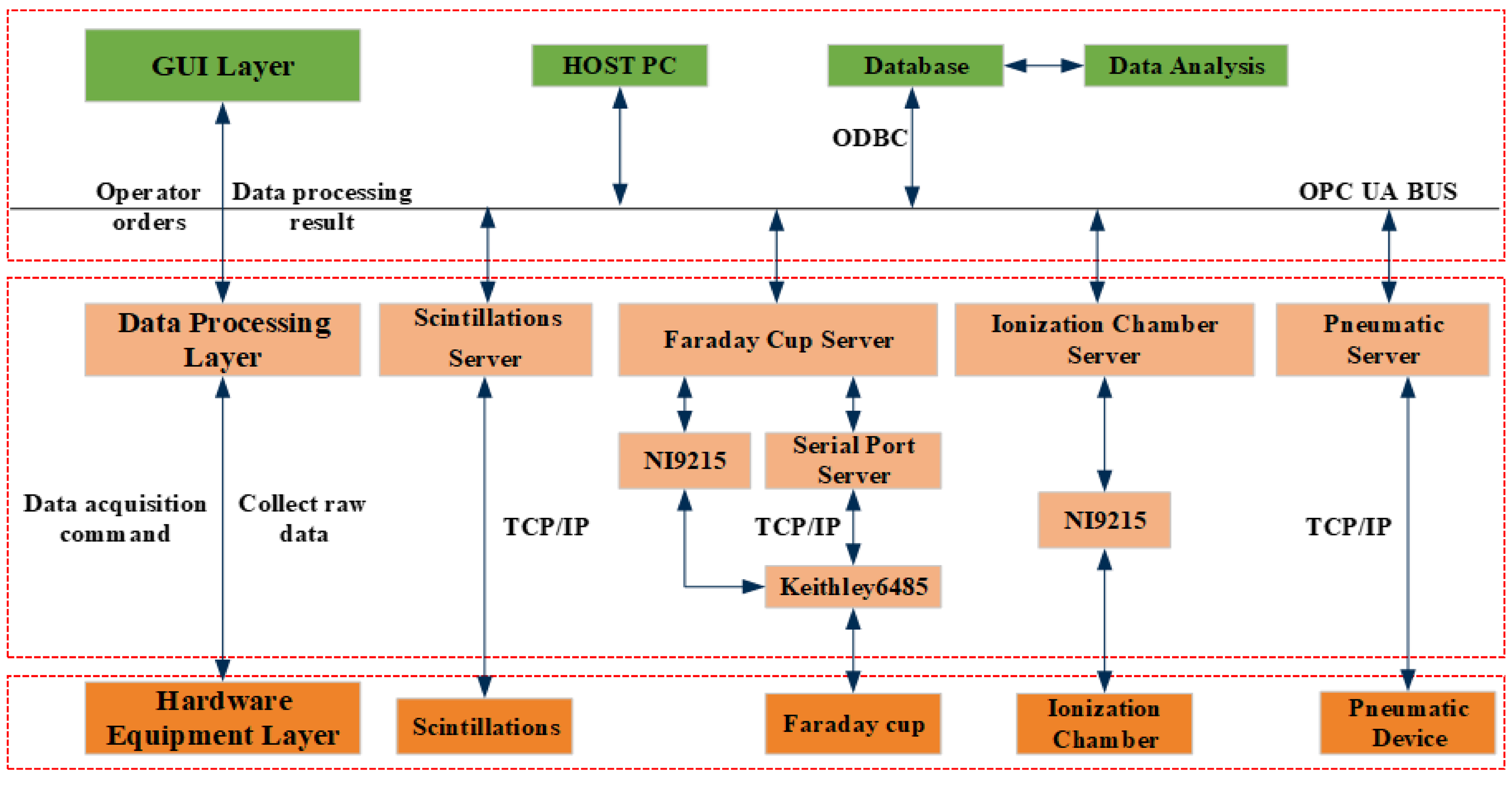

Fig. 2 Architecture of HUST-PTF Beam diagnostic system

As a subsystem of the accelerator system, the HUST-PTF beam diagnostic system is mainly composed of hardware (beam detector) and software (control system). The entire beamline contains 21 scintillators, 6 Faraday cups and 6 ionization chambers. These probes can be used to measure beam profile, position and intensity.

Table 1 Beam parameters at two position

Parameters	Accelerator exit	After degrader
Bunch frequency	75MHz,CW mode	75MHz,CW mode
Energy	250Mev	70-240MeV
Intensity	60-500nA	0.4-5nA
Energy spread	0.3%	0.3%-0.7%
Emittance	2-5mm mrad	5-10 mm mrad

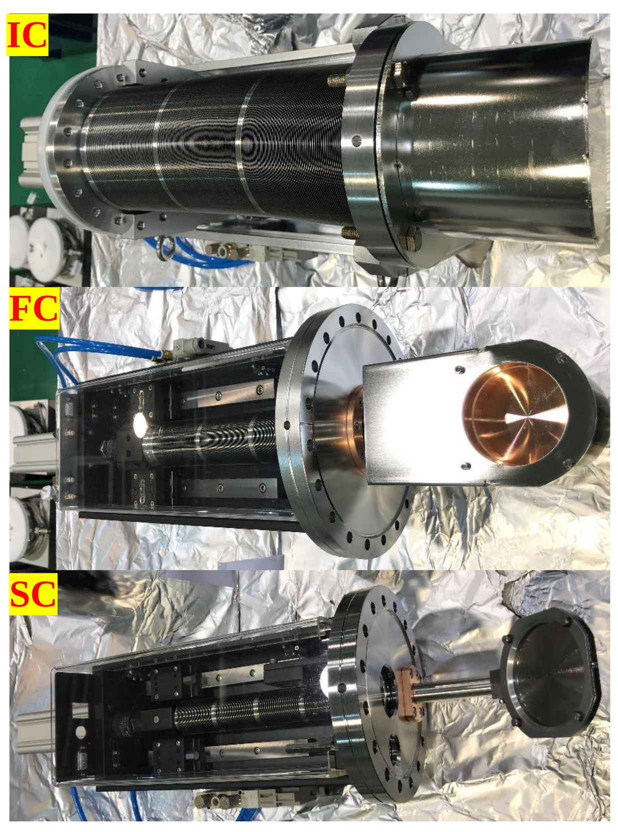

Fig. 3 Prototypes of the SC, FC and thick IC. All the detectors are driven by pneumatic device

Detectors and Software of HUST-PTF Diagnostic System

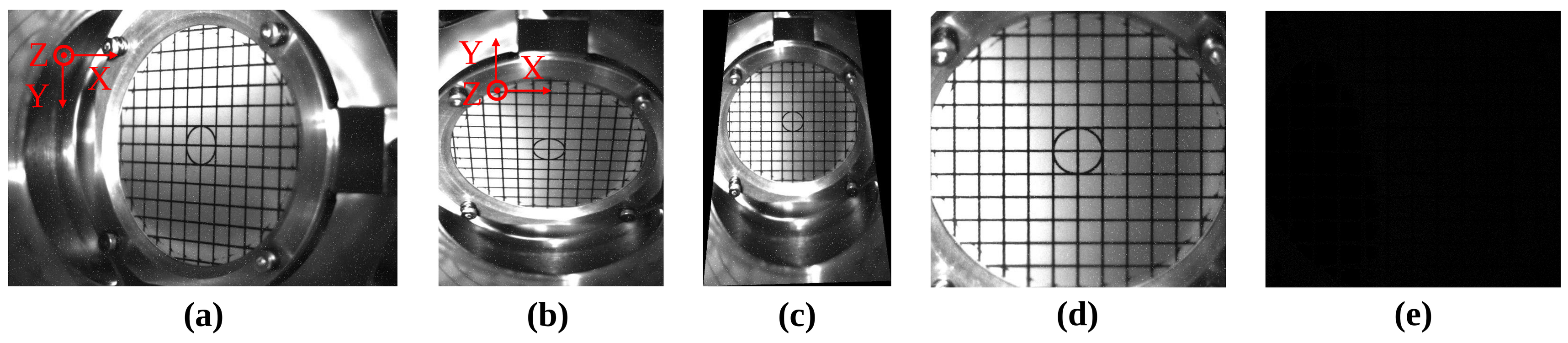

Fig. 3 Image processing of scintillation system. (a) raw image with 1626×1236 chip pixel; (b) rotated image; (c) spatial perspective correction of the image; (d) cropped image; (e) image after removing the background with approximately 850×850 chip pixel.

- **Scintillation System**

Camera : **Basler acA1600-20gm**
Screen : **60mm×60mm Al_2O_3 by IMP**
Original pixel : **1626 ×1236**
Final pixel : **approximately 850 × 850**
Optical resolution : **0.07mm/pixel**
Storage format : **8 bit binary matrix**

By integrating the matrix in the horizontal and vertical directions, the one-dimensional Gaussian distribution in both directions can be obtained, that is:

$$f(k) = A\frac{1}{\sqrt{2\pi\sigma_i}}e^{\frac{(k-\mu_i)^2}{2\sigma_i^2}} \quad (i = x, y)$$

where f represents the beam spot brightness in an 8-bit binary format, A is a constant, σ_i is the size dimensions of the beam spot, and μ_i is the central positions of the beam spot.

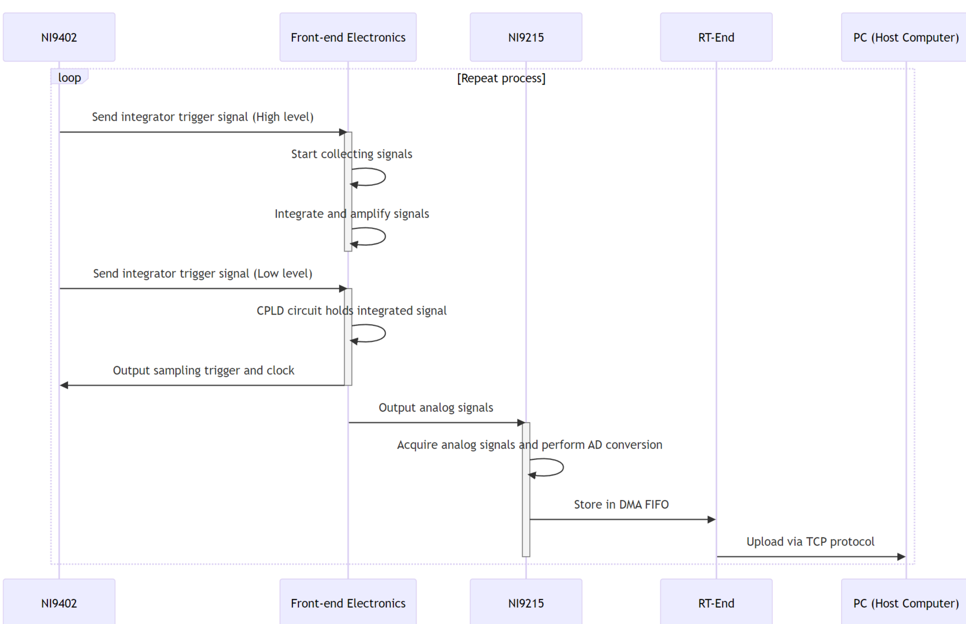

Fig. 5 Operating logic diagram of the ionization chamber

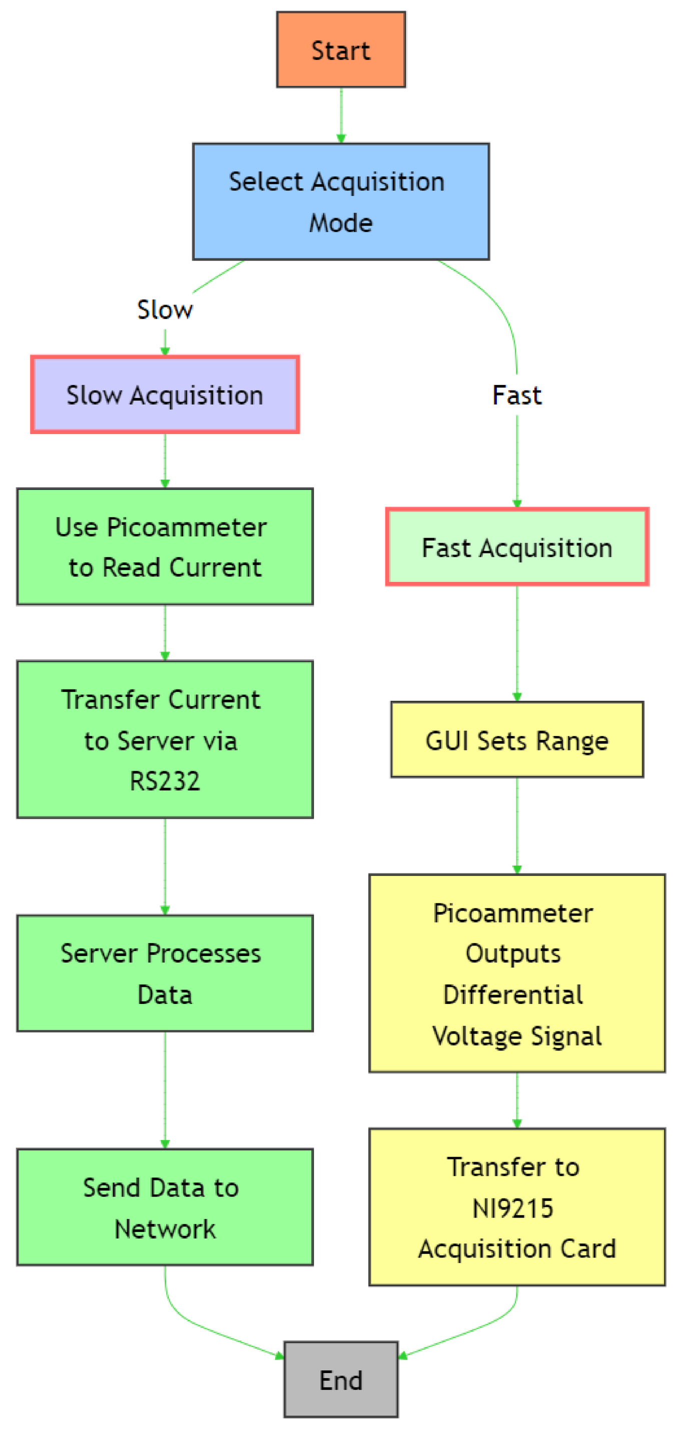

Fig. 4 Faraday Cup workflow

All data will be stored individually in the beam diagnostic system's database and also published on the bus as OPC UA variables, making them easily accessible for the beam control system (BCS).

Conlusions

The HUST-PTF beam diagnostic system is efficient to control all the detectors on the transport lines, and is responsible for the analysis, processing and transmission of the data collected by the three types of detectors. For different detectors, the diagnostic system has different methods. The scintillation needs to focus on processing image information to obtain the transverse size of the beam. Faraday cup has two type of current measurement methods: slow and fast. The ionization chamber needs to control multi-channel AD sequential sampling to obtain dimensional information in X and Y directions.

In addition, the HUST-PTF beam diagnostic system is also the node where the beam diagnostic part interacts with the BCS data information and commands. It will play an important role in beam tuning in the future.

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