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The control system of the multi-strip ionization chamber for the HIMM

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ABSTRACT

Heavy Ion Medical Machine (HIMM) is a carbon ion cancer treatment facility which is being built by the Institute of Modern Physics (IMP) in China. In this facility, transverse profile and intensity of the beam at the treatment terminals will be measured by the multi-strip ionization chamber. In order to fulfill the requirement of the beam position feedback to accomplish the beam automatic commissioning, less than 1 ms reaction time of the Data Acquisition (DAQ) of this detector must be achieved. Therefore, the control system and software framework for DAQ have been redesigned and developed with National Instruments Compact Reconfigurable Input/Output (CompactRIO) instead of PXI 6133. The software is Labview-based and developed following the producer–consumer pattern with message mechanism and queue technology. The newly designed control system has been tested with carbon beam at the Heavy Ion Research Facility at Lanzhou-Cooler Storage Ring (HIRFL-CSR) and it has provided one single beam profile measurement in less than 1 ms with 1 mm beam position resolution. The fast reaction time and high precision data processing during the beam test have verified the usability and maintainability of the software framework. Furthermore, such software architecture is easy-fitting to applications with different detectors such as wire scanner detector.

1. Introduction

The multi-strip ionization chambers are used to measure the transverse beam profile and intensity in a dedicated Heavy Ion Medical Machine (HIMM) [1]. Such newly developed detectors have two cathodes and two strip anodes which are oriented along the vertical and horizontal directions and this detector can measure the transverse beam profile of carbon ions with energy ranging from 80 MeV/u to 400 MeV/u [1,2]. An assembled multi-strip ionization chamber which was tested in radioactive ion beam (RIB) production and transfer line two (RIBLL2) of the Heavy Ion Research Facility in Lanzhou cooler storage ring (HIRFL-CSR) is shown in Fig. 1 where the sensitive area is $74 \times 100\ \text{mm}^2$ corresponding to 64 strips for both horizontal and vertical directions. This type of detector can be produced with different sensitive areas and accuracy in order to satisfy different physical and clinical treatment requirements.

The data acquisition (DAQ) system for this type of detector was initially based on NI PXI 6133 [1,3]. However, the machine automatic beam commissioning and beam position control must be implemented in the HIMM according to the requirement of extracted beam position stability. Therefore, the NI CompactRIO which runs on real time (RT) system with fast calculation on field-programmable gate array (FPGA) was selected to substitute the NI PXI 6133. Meanwhile, the volume usage for the NI CompactRIO system is much lower than the NI PXI products. As a result, a new software framework based on NI CompactRIO has been developed to upgrade the data acquisition and control characteristics for the multi-strip ionization chambers and for similar detectors. Details of the control system architecture, main test results and performance are described in the following sections.

2. Control system architecture

In order to complete the automatic beam commissioning and beam position control functions and build a homogeneous, timing-saving development, high maintainability and expansibility of control system for different detectors, a new systemic software framework was designed and developed. In order to complete the requirements for beam position control, 1 mm beam position resolution must be achieved by using the acquired data. Furthermore, the data acquisition, data analysis and data transmission must be accomplished in less than 1 ms to stablilize the extracted

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beam for the automatic commissioning. The overall control system architecture for multi-strip ionization chamber is subdivided into three layers as illustrated in Fig. 2 and described as follows.

Layer (1) is the interactive graphical user interface (GUI) for the accelerator operators and end-users. The acquired data and consequent calculation results are displayed in this layer. Additionally, the operational status such as the data acquisition status, transmission status and control commands implementation status are monitored and displayed by this layer.

Layer (2) is the data acquisition tier which is the core of the control system and it is an integrated system-NI CompactRIO enclosed in a 4 slot chassis which combines an industrial real-time controller and reconfigurable FPGA for industrial machine control and monitoring applications [4]. The DAQ tier communicates with layer (1) by the TCP/IP protocol and NI network shared variables (NSVs).

Layer (3) includes the detectors with front-end electronics which interact with the RT target through the field bus links. All the data used and generated, including the detector raw data from the readout, the processed beam profile information and the control system status, will be finally stored in the database.

2.1. Updated hardware

The former control hardware for multi-strip ionization chamber was based on the NI PXI 6133, which is an 8 simultaneously sampled analog input, characterized by a maximum throughput of 2.5 MS/s or 3 MS/s in warp mode [3]. However, the present control system is based on the NI CompactRIO to substitute NI PXI 6133. The detailed reasons that lead to the selection of the NI CompactRIO system for this application are described as follows [4]:

1) During the beam calibration for particle therapy in the HIMM, the beam is steered by steering magnets in accordance with the deviations of the beam positions measured by the multi-strip ionization chamber from the expected values. In this commissioning procedure, less than 1 ms of data analysis and transmission time is needed for adjusting the steering magnet fast. While the PXI 6133 integrates the signal in 800 μs, acquires the data in 200 μs and computes the beam position in more than 50 ms, the CompactRIO runs on an industrial RT controller and performs data acquisition, recording, analysis and transmission in less than 1 ms.
2) For NI CompactRIO system, the industrial mechanical design characteristics such as small size, extreme ruggedness, and fanless provide easy field installation and stability.
3) The beam data position resolution measured by the NI PXI 6133 and the NI CompactRIO system is the same. However, the industrial cost for the NI CompactRIO system is lower than that for the NI PXI 6133.

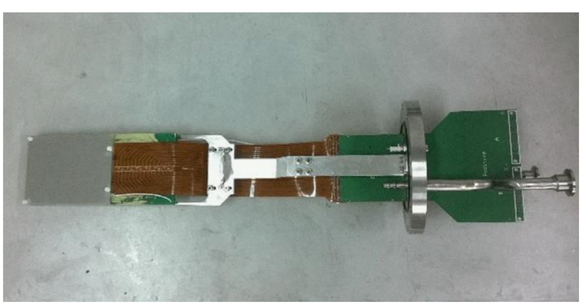

Fig. 1. Assembled multi-strip ionization chamber.

2.2. Software framework

The software framework is mainly based on the message mechanism, modularity technology and is structured by Labview queued producer–consumer pattern [5]. The components' concepts and data interaction flow of the software framework are illustrated in Fig. 3. This software framework has been designed and developed based on components' concepts and on the base libraries which run on the host PC part, RT part and FPGA part. The components are independent functional modules with high cohesion and loose coupling character. Base libraries are used by the other modules and customized according to the properties and methods of the functional modules.

The components call the base libraries to organize different modules which are used to complete different functions. They are actually independent functional modules which include one or more threads running in parallel and can be reused for different applications. The main components, described in the following sections, are the message center module, the data acquisition module, the data transmission module and the data processing module.

2.2.1. Components' concepts

The FPGA part is in charge of acquiring the beam current from the front-end electronics of the multi-strip ionization chamber under the control of the trigger and sampling clocks. The code running on the FPGA part is in charge of data acquisition from front-end electronics and transfers the data to RT target by direct memory access-first in first out (DMA-FIFO).

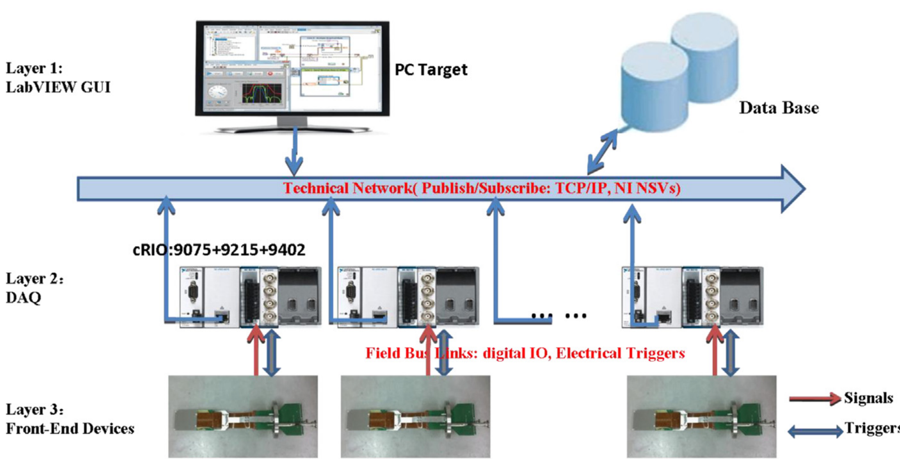

Fig. 2. Architecture of control system for the multi-strip ionization chamber.