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A modular data acquisition system for reconstruction of radiation dose spatial distribution in radiotherapy treatment planning

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A R T I C L E I N F O

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A B S T R A C T

In this work we propose the complete Data Acquisition (DAQ) system for measurement of volumetric radiotherapeutic dose deposition in tissue-like phantoms based on 3D printed plastic scintillators. The DAQ is easily extensible thanks to the modular architecture of its hardware and software components. We show results from the full measurement chain indicating proper operation of the system.

1. Introduction

Cancer is one of the deadliest diseases worldwide, accounting for nearly ten million deaths in 2020 [1]. Half of the cancer-diagnosed patients undergo photon therapy procedures. However, treatment planning is a very complex process involving knowledge of radiation dose spatial distribution in and around tumor volume which is very hard to predict exactly with current methods.

To solve that problem, we propose the state-of-the-art Data Acquisition (DAQ) system for measurement of dose deposition in human tissue phantoms based on plastic scintillators. The DAQ system is the key component of the project entitled *Reconfigurable Detector for Measuring the Spatial Distribution of Radiation Dose for Applications in the Preparation of Individual Patient Treatment Plans*, which is concurrently under the development [2,3].

2. Materials and methods

System architecture. The DAQ consists of the custom-designed hardware with the embedded firmware and software managing system operation (Fig. 1). The basic hardware unit is called *slice*, being a set of Printed Circuit Boards (PCBs) containing: (i) 8×8 Multianode Photomultiplier (MA-PMT) assembly amplifying photon flashes from irradiated scintillators via optical fibers, (ii) front-end readout Application Specific Integrated Circuit (ASIC) [4] allowing simultaneous measurement of photon counting and energy from 64 independent channels, (iii) a Field-Programmable Gate Array (FPGA) with Ethernet-based *slice* control firmware [5] enabling configuration and data exchange over UDP/IP. Each *slice* is entirely operational on its own, however, in order to provide a sufficient number of channels in the system, they can work in parallel (the prototype system will be composed of 1024 readout channels) and their operation will be synchronized with Precision Time Protocol (PTP) to ensure correct event time stamping.

On the other end, there is a Server Application written in Python programming language whose main responsibility is to establish a reliable connection to all functional blocks of each *slice*. To do so, it recreates the logic scheme of the FPGA firmware submodules in terms of Proxy Nodes. They process requests and data concurrently as threads, which optimizes Central Processing Unit (CPU) and memory utilization, but it would not be possible without the special Python fork removing multithreading mutex [6]. The collected data from all *slices* will be then accessed through the TCP/IP server by consumer widgets for online system monitoring, data archiving or visualization in a similar way to the system described in [7].

Measurement procedures. The energy measurement is done by means of slow shaper being part of the ASIC such that the maximum signal value

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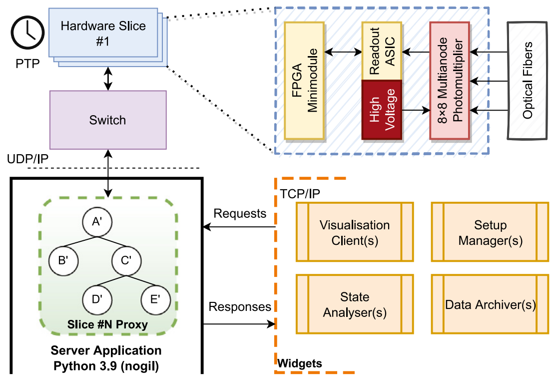

Fig. 1. Data Acquisition (DAQ) system overview.

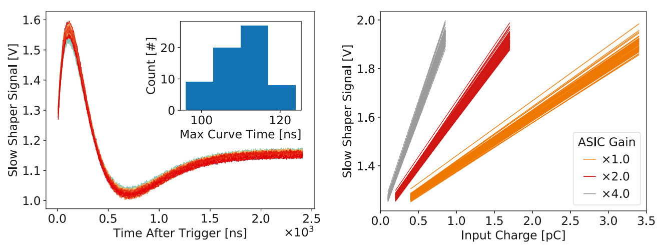

Fig. 2. Slow shaper signal curves, inset—maximum value delay distribution (left), selected response curves (right).

of its response is proportional to the input charge [8]. To measure the optimal delay for amplitude sampling, for each channel 2 pC charge was injected to effectively simulate MA-PMT output.

Then, the linearity of the system was measured for a set of ASIC gains by injection of charge between 0.1 and 3.5 pC.

Finally, the photon counting capability was tested with a 660 nm laser source directly illuminating selected MA-PMT anodes thanks the precise three axis positioning system. Laser was producing very short bursts of light at 1 kHz rate. The measurement setup was enclosed in a light-tight box to prevent false counts from the environment.

All tests characterize a single 64–channel *slice*.

3. Results and discussion

The slow shaper signal curves are presented in Fig. 2 (left). All channels follow the same shape and the curve maxima fall between 100 and 120 ns after charge injection. Following, for each ASIC channel, gain and input charge combination response curves preserve very good linearity in a whole dynamic range of the ASIC operation (Fig. 2; right plot).

Full system data reliability depends on measurable multiple components e.g., optical losses in fibers, MA-PMT and ASIC amplification factors per each channel in each *slice*. Obtained distributions (for test pulses) of ASIC channel gain and offset follow gaussian distributions with σ/μ ratio less than 3 % and 0.7 % respectively (Fig. 3).

The example snapshots from the photon counting test procedure are visible in Fig. 4. As expected, the targeted MA-PMT channels responded with rates close to 1 kHz. On the other hand, the closest neighboring channels present <7 % relative pulse rate which might be caused by the laser spot size comparable with the size of the MA-PMT cell. The rest of the channels had relative activity below 1 % with the majority of them staying inactive most of the time.

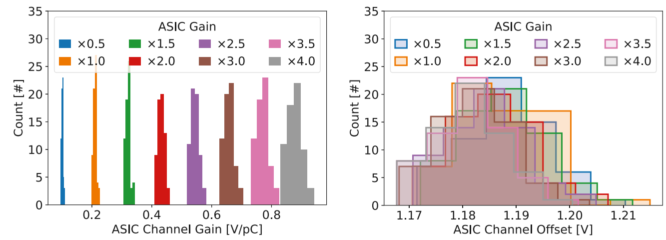

Fig. 3. ASIC channel gain (left) and offset (right) distributions.

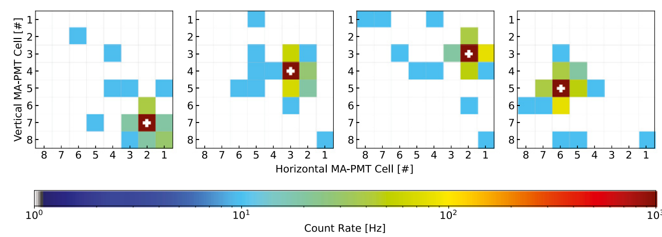

Fig. 4. Example results of a MA-PMT illumination scan; anodes targeted by laser are marked with white cross signs.

4. Summary

We showed that the proposed DAQ is working and providing desired outputs in terms of signal quality and overall system reliability. Further development will concentrate on systematic system energy calibration, software upgrades enabling easier measurement procedures and integration with scintillator-based phantoms.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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