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PARALLEL PROCESSING SYSTEM FOR BIG DATA IN PRECLINICAL COMPUTED TOMOGRAPHY

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Abstract. This paper reports the main ideas in a recent project proposal done in the scope of medical imaging systems. We target the THCORBA micro-pattern gaseous detector that has been demonstrated to be a robust device providing multi-slice acquisition and 3D reconstruction. Given the current acquired signal processing times, image reconstruction and post-processing tasks have to be improved. The paper summarizes some of the ideas of such an improvement, proposing to delegate certain post-processing tasks to programmable logic devices with the intention to parallelize the required filtering and calculations that would allow to increase the throughput.

Keywords: Computed Tomography, Spectral Detection, Micro-pattern Gaseous Detectors, Programmable Logic, FPGA, Parallel Computing.

Introduction.

The role of Big Data analytics in medical image processing has been growing significantly over the past decades [1]. Computed Tomography (CT) is one such medical imaging modality that has revolutionized medical diagnosis, being nowadays widely used in hospitals for prompt imaging services. Besides of medicine, CT is also employed in forensic, archaeological, biomedical and industry quality control applications [2]. To achieve stable operation and fulfil increasing CT imaging requirements spectral detection technologies need to be improved. Micro-pattern gaseous detectors (MPGDs) are a group of gaseous ionization detectors consisting of microelectronic structures with sub-millimeter distances between anode and cathode electrodes. MPGDs have a number of benefits, such as good energy resolution, full 2D field-of-view, electronic noise rejection, unlimited dynamic range, good count-rate (>1MHz/mm^2), soft X-ray detection (<1 keV), room-temperature operation, large detection areas

(>30×30 cm^2), versatility and portability, and low production and maintenance cost (as opposite to solid-state detectors) [3]. Recent advances in MPGDs have enabled the possibility of multi-slice computed tomography to incorporate spectroscopic information into CT.

In this work, we target the development of a low-cost portable multi-slice CT system using MPGDs with energy resolving capability for full body small-animal imaging applications in preclinical research. This detector concept has the unique capability to store, not only the interaction position, but also the energy information of each single photon as opposed to detectors of conventional CT systems and other spectroscopic detectors.

This proposal grounds on the previous work [3-6] and aims at optimization of detector's operation, development of required software and design and assembly of a low-cost CT system with spectral capabilities to apply in preclinical research for full body animal imaging. As a target, MPGD THCORBA [3-6] was considered as a robust detector providing multi-slice acquisition and 3D reconstruction. Although THCOBRA already showed potential for spectral X-ray imaging, further developments are required to improve image reconstruction and post-processing. Figure 1 illustrates the THCOBRA layout and operating principle.

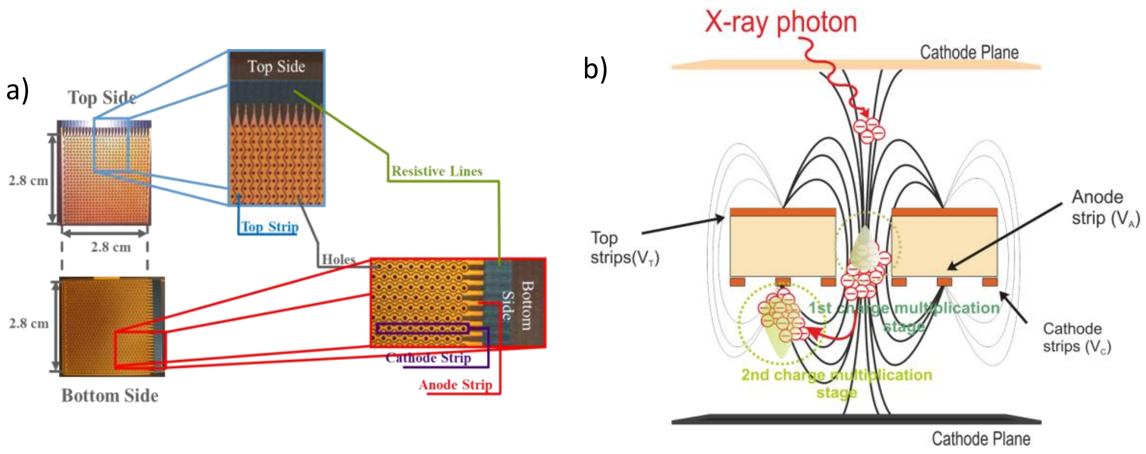

Figure 1. THCOBRA layout [6] (a) and representation of the THCOBRA operating principle [5] (b)

Among other project's tasks, one is related to the development of a dedicated portable electronic system for detector bias and readout, which will lead to systems' portability. After collection at the anodes, the load is conducted to the resistive lines, where it is divided into two pulses, collected at the line terminals by pre-amplifiers and then processed in an ADC, one channel for each signal. The collected information results in huge amount of data needs to be processed, in similarity to other preclinical computer tomography imaging studies [7]. Due to the large amount of the acquired data, reconstruction is a very time-consuming process.

Related work.

Development of a portable and scalable multi-channel readout data acquisition systems has been explored in several works. Most of them recur to CPU/GPU computational platforms that perform processing outside of the data acquisition chain [8-9]. There exist solutions exploring FPGAs as signal processing units and coincidence finders [9-13]. In [10] a more complete data acquisition system is proposed based on Xilinx Zynq programmable system-on-chip (SoC), which uses Gigabit Ethernet transceivers for communication and is capable to reconstruct images on the fly for a positron emission tomography scanner built of plastic scintillators. All the explored solutions are specific for a particular type of detectors. There exist no fast and scalable data processing system for the THCORBA detector. In the current version, a CAEN 1728A NIM module [14] is used to readout the charge pulses, which is equipped with four ADCs having a resolution of 14 bits and a 100 MHz sampling rate. The module performs real-time digital signal sampling and shaping, as well as data storage for offline analysis [15]. The acquired data analysis is executed in Matlab and consists of reading EVT files (usually several files for acquisition), performing timing coincidence of four channels to eliminate events that are out of the coincidence window, calculation of the coordinates and the energy and, finally, image reconstruction. In case of multiple EVT files very long processing times are required (up to an hour).

Development of Electronics and Mechanical System.

A PCB for detector bias and readout will be designed to include variable high voltage power module with ultralow noise and an analog to digital converter (ADC) with four channels to digitize the signals from the detector readout. We plan to recur to field-programmable technology and to use an FPGA-based board to process data from the ADC, applying as much parallelism as possible, and finally sending the result to a PC for data analysis. A user-friendly interface will be developed that will allow the control of operation parameters and data acquisition.

An FPGA technology will be used to efficiently process data received from the detector. There are several reasons for such an option and the most important are the inherent configurability of FPGAs and relatively cheap development cost. FPGA-based systems can be specified, simulated, synthesized, and implemented using dedicated integrated computer-aided design environments. Experiments and explorations of such systems are commonly based on prototyping boards that are linked to the respective design environment. We plan to explore both simple FPGA-based boards and recent field-configurable microchips incorporating scalar and vector multi-core processing elements and reconfigurable logic appended with a number of frequently used devices. It should be mentioned that the cost of the most advanced FPGA devices is high, and cheaper FPGAs support clock frequencies that are much lower than those in a PC. Obviously, to achieve acceleration with devices that are generally slower, parallelism needs to be applied extensively and this will be explored.

In particular, the data received from ADC are stored in an EVT file that in the current system version is processed in Matlab software. The processing includes elimination of all the stored events that are not within the defined time window. For this step, the coincidence time window is chosen, the times of pile-ups and whether or not we want to consider pile-up events. As a result, a new MAT file created containing the saved data and allowing to calculate the coordinates of the photon position and energy according to the following equations:

$$x = k \times \frac{x_A}{x_A + x_B}$$
$$y = k \times \frac{y_A}{y_A + y_B}$$
$$Energy = l \times (y_A + y_B)$$

where k is an arbitrary constant, x_A and x_B are, respectively, the pulse amplitudes measured at the ends of one resistive line and y_A and y_B the pulse amplitudes at the ends of the other line.

The EVT file size is about 100 MB leading to long processing times. We believe that introducing a field-programmable gate array SoC platform connected directly to data streams coming from ADCs can perform event building, filtering, and coincidence search by programmable logic in real time.

The required operations are in line with the methods reported in [16-17], which however cannot be applied directly to large sets of data. The main idea is working with blocks of data with limited complexity, in such a way that, large data sets are decomposed on blocks and completing the applied operations (within the blocks) makes possible to further handle large blocks of data instead of individual items. A good example is merge sorting in which the preliminary sorted blocks are merged in concurrently executed computational units. Thus, items in the blocks are sorted in very-high speed hardware accelerators with subsequent merging of the sorted blocks in parallel software [16].

Recent reconfigurable accelerator platforms, such as Versal [18] are excellent choices for data-intensive workloads running datacenters, mainly because of integrating traditional FPGA programmable fabric, software programmable processors and software programmable accelerator engines. Despite this, we plan to target more modest and relatively cheap microchips, such as Zynq SoC [19], which provide efficient interfaces for data exchange between processing units and programmable logic and support both software and hardware development. Suitability of Zynq devices for the intended type of processing has already been proved in [10].

The current and the proposed data acquisition and processing chains are depicted in Figure 2. The main difference is in delegating the acquired and digitized signal processing to a programmable SoC.

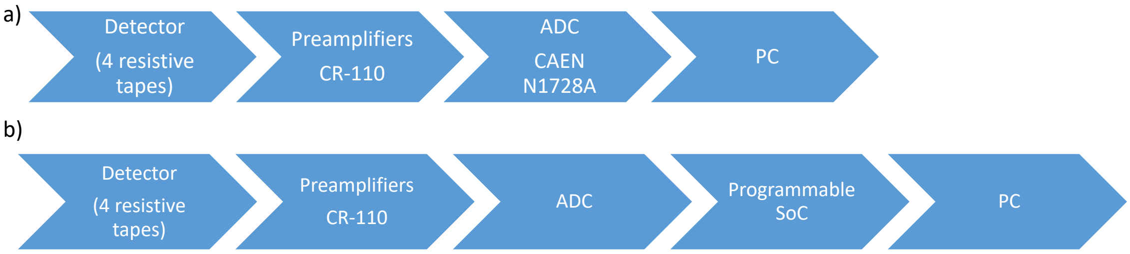

Figure 2. The existing data acquisition and processing chain (a) and the intended chain (b)

Conclusion

This paper summarizes the project proposal (submitted to a national science foundation) dedicated to further improvement of the THCORBA detector for which image reconstruction and post-processing have to be improved to allow a speedy process and system portability. We believe that the described system has strong potential for industrial applications, not only in biomedical imaging, but also in forensic sciences, archaeology and industry quality control.

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