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Eryk Czerwiński, Marcin Zieliński*, Tomasz Bednarski, Piotr Białas, Łukasz Kapłon, Andrzej Kochanowski, Grzegorz Korcyl, Jakub Kowal, Paweł Kowalski, Tomasz Kozik, Wojciech Krzemień, Ewelina Kubicz, Marcin Molenda, Paweł Moskal, Szymon Niedźwiecki, Marek Pałka, Monika Pawlik-Niedźwiecka, Lech Raczyński, Zbigniew Rudy, Piotr Salabura, Neha Gupta Sharma, Michał Silarski, Artur Słomski, Jerzy Smyrski, Adam Strzelecki, Anna Wieczorek, Wojciech Wiślicki and Natalia Zoń

Database and data structure for the novel TOF-PET detector developed for the J-PET project

Abstract: The complexity of the hardware and the amount of data collected during the PET imaging process require application of modern methods of efficient data organization and processing. In this article, we will discuss the data structures and the flow of collected data from the novel TOF-PET medical scanner that is being developed at the Jagiellonian University. The developed data format reflects the registration process of the γ quanta emitted from positron electron annihilation, front-end electronic structure, and required input information for the image reconstruction. In addition, the system database fulfills possible demands of the evolving J-PET project.

Keywords: DAQ; database; positron emission tomography (PET); scintillating detectors.

Introduction

Current novel positron emission tomography (PET) scanners [1–8] are complex devices built from hundreds of small scintillating detectors that register large amount of data that need to be handled and processed. For the J-PET project, a new framework was developed [9] to control data processing and reconstruction. Such framework can run in an environment that provides sufficient data capacity, read-write speed, and CPU power [10]. To optimize speed for both reconstruction code development and data analysis, new data structure and database were created.

Definitions: from e^+e^- annihilation to input for image reconstruction

A single event of one positron-electron annihilation can be reconstructed in the J-PET system only when two hits from created γ quanta were registered exactly in two scintillator strips. Light emitted in the scintillator from one of these hits will travel along the strip and can be registered by photomultipliers (PMs) attached to its ends. The analog signal from the PM is probed at defined number of thresholds (N_{th}) by front-end electronics (FEE) [11, 12] together with the integrated charge of the signal and is stored in binary format. In the ideal case, one e^+e^- annihilation gives two hits in the opposite scintillator strips, which are then registered as four signals in the PMs. Finally, a single annihilation event is stored at the $4\times(N_{th}+1)$ channels. The FEE developed for the J-PET project allows for trigger-less mode of data processing [11]. The time of all registered signals is measured with respect to the clock distributed among all electronic elements, and therefore, the time registered at specific channel (when signal crosses given threshold) is related to a time slot.

***Corresponding author: Marcin Zieliński,** Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, 30-059 Kraków, Poland, E-mail: Marcin.Zielinski@uj.edu.pl
Eryk Czerwiński, Tomasz Bednarski, Piotr Białas, Grzegorz Korcyl, Jakub Kowal, Tomasz Kozik, Wojciech Krzemień, Ewelina Kubicz, Paweł Moskal, Szymon Niedźwiecki, Marek Pałka, Monika Pawlik-Niedźwiecka, Zbigniew Rudy, Piotr Salabura, Neha Gupta Sharma, Michał Silarski, Artur Słomski, Jerzy Smyrski, Adam Strzelecki and Natalia Zoń: Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Kraków, Poland
Łukasz Kapłon: Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, Kraków, Poland; and Faculty of Chemistry, Jagiellonian University, Kraków, Poland
Andrzej Kochanowski, Marcin Molenda and Anna Wieczorek: Faculty of Chemistry, Jagiellonian University, Kraków, Poland
Paweł Kowalski, Lech Raczyński and Wojciech Wiślicki: Świerk Computing Centre, National Centre for Nuclear Research, Otwock-Świerk, Poland

J-PET basic elements

Scintillator strips are used to register γ quanta in the described tomograph device. The light collected at the end of each strip is converted to an electric signal by the attached PM. Signals from several PMs attached to a single FEE board are distributed to the N_{th}+1 channels. A map of connections between scintillator, PM and FEE elements is stored in the dedicated database. This allows to relate the single-output channel from the FEE to a given threshold or charge of a signal registered by a specific PM connected to a known scintillator strip. The schematic view of the connection between J-PET basic elements is presented in Figure 1.

Reconstruction steps as data structure

The analysis steps of the J-PET data inside a developed framework correspond to the detector-FEE structure and physical process of annihilation event registration. Binary data from FEE are unpacked to the RootTree format [13]. In the next step, the data are ordered into the structure that reflects the detection system and FEE connections based on the information about the current J-PET setup from the database. At this stage, data can be corrected with calibration constants. An example of time calibration procedure is described in reference [14], and PM gain determination can be found in [15]. After applying time calibration constants, the processed data can be converted from the time slot to the true time of the event, which allows the grouping of registered values at different channels into separate signals. Determination of time and position of the hit is based on the paired signals and reconstruction method [16, 17]. Finally, paired hits constitute input for further image reconstruction [18–20].

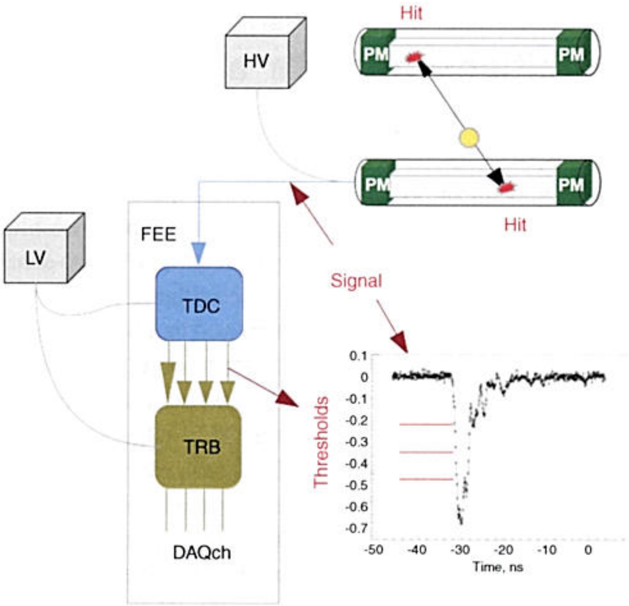

Figure 1 Schematic view of the annihilation event (yellow dot) and two hits of γ quanta registered in two scintillating strips at J-PET. The light from each hit is converted to electronic signal by two PMs. In the given example, one signal is probed by FEE at three thresholds, and additional information about charge of the signal is registered. For simplicity, only two scintillator strips are shown, and the electronics for only one PM is presented.

J-PET database design and structure

For the medical records of the patient treatment, all information about measurement conditions should be preserved. One needs to store all the information about the hardware used in the measurement, alignment of the detectors, initial setup parameters, calibrations, and the software configuration. In addition, all these settings have to be saved for each single measurement and available at any time for offline data processing and analysis as well as for the backward compatibility.

To comprehend the majority of the different types of data, we developed and implemented the object-relational database model based on the open-source PostgreSQL engine (http://www.postgresql.org), which is an object-relational database management system. It features very high stability, flexibility, and scalability. Furthermore, it provides a variety of extensions for different systems, data types, operators, methods, views, aggregates, and procedural languages.

A logically developed database is organized into three main parts:

1. information about hardware properties and operational parameters such as maximal high-voltage values for the PMs,
2. actual configuration of the setup, detector alignment, and parameters such as thresholds set on the FEEs,
3. settings for each single measurement, as a readable log for later offline analysis of data.

The logic structure of the database is shown in Figure 2.

Information about the hardware in the database contains an inventory list of all the equipment and its major properties that are used and available for the project of the novel PET device. It holds the details of high- and low-voltage suppliers (numbers of output channels), scintillator

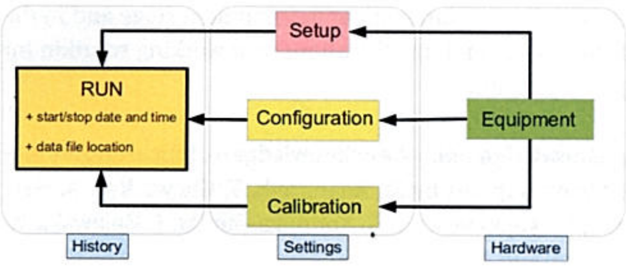

Figure 2 Schematic view of the implemented database logic.
At the given schema, three logic parts of the database are seen: hardware, settings, and history.

strips (dimensions), PMs (maximal value of high voltage for safety purposes), FEE (number of input, output channels), types of radiation sources, and phantoms. Each single part of equipment has its own unique identification number, which allows for easy identification of the hardware. For each hardware part, the status value can be set to distinguish the situation for the broken, terminated, available, and in use element. This ensures that the part that is, e.g., broken will not be used in current setup by accident. Furthermore, all the operations such as adding, deleting, and changing of the status of particular equipment are logged per user and stored in the database.

Moreover, some of the hardware (PMs, scintillators, and FEEs) need an initial calibration before usage in the measurement. In the developed database, a separate unit within the hardware part is responsible for holding the calibration constants. This solution ensures the possibility of changing the calibration at any time in the future and also stores the history of previously used values.

For the real measurement with phantoms, and in the future, for patient examination, the hardware has to be assembled together and connected physically and logically. This structure of connections is mapped into the software as a setup. Every connection in the setup is represented by a single entity in the database, and it references to two setup objects. The connections among the HV channels, PMs, and scintillators are established. Later, a sequence of FEE channels is defined; therefore, each setup contains information about connection configuration. Configuration is created for a single connection between two sides of a setup objects and holds the specific information for the connection such as threshold set on specific channel in the FEE board. In the process of setting up the connection and configuration between particular elements, a simple logic mechanism is implemented, which ensures, i.e., impossible to set a high voltage above safety limit stored for that element. Aside from the connections, every setup references the time/date properties and stores the information about the user who created the setup. It features as well the possibility of cloning the setup, which allows for very easy modifications of the present setup and keeping the old one in the history.

Apart from the setup, each conducted measurement has to be stored with the information containing time and date, description, path to collected data, used setup, and the optimal calibration. This functionality is implemented as a run table in the database and containing all the important details of each single measurement. Utilizing this feature, one can perform offline data analysis and, if needed, restore every specific parameter used during the measurement.

For database handling and user usage, a native application written in object-oriented C# language [21] was developed. It offers all the features of modern graphical user interface, ensuring easy access to all the units of the database, enabling addition, deletion, updating, and modification option of each hardware, setup/connection, or run sections.

Data flow and data storage

In the presently developed PET prototype, annihilation events are registered by the scintillators and PMs attached to its ends, from which signals are gathered by FEE boards, and then the DAQ system saves them to disk. Data collected in this manner are then used for offline analysis and medical image reconstruction. Therefore, admittance to collected data should be fast and efficient with possibility of secure access from external locations. For that purpose, we have developed a way to ensure secure data storage and handling using local resources and external data storage. The workflow of the data after it is being processed by the DAQ is presented in Figure 3.

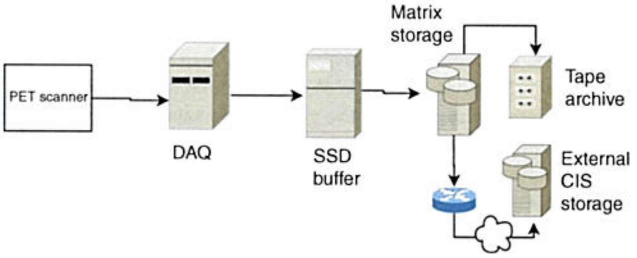

Figure 3 Schematic view of the implemented data flow and storage.
Data collected from the PET scanner by DAQ system will be saved to the data matrix and preserved on external CIS storage. Additional backup will be done with the tape archive.

The amount of collected data will be approximately few megabytes per second, which will be then saved in the files of size not exceeding 10 GB. Assuming measurements are performed 40 h/week and 52 weeks/year, this makes around 100 TB of data collected per year. Data coming directly from the DAQ system will be saved to a fast SSD buffer. Later on, it will be moved to temporary storage from which data will be sent to a permanent cloud data storage in Świerk Computing Centre (CIS) (http://www.cis.gov.pl) once a day. For the purpose of offline analysis, one will need to request specific data sample from the CIS cloud storage, which will then be securely downloaded to a disk matrix, coupled with a computing cluster used for the analysis. Additionally, for security reasons, it is planned to preserve data collected during every measurement using the tape archive.

In the future, the workflow of the data will be organized based on cloud and grid computing as presented in reference [10] to enable optimal data saving, processing, and fast medical image reconstruction.

Summary

The presented structure of data and database are the currently working solutions in the last phase of development. The database structure is already tested and running. In addition, the database graphical interface is being currently tested. The system is designed to keep all settings during the measurement at development stage and in the future with small modifications as a working solution for J-PET detector.

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