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

J-PET analysis framework for the prototype TOF-PET detector

Abstract: Novel time-of-flight positron emission tomography (TOF-PET) scanner solutions demand, apart from the state-of-the-art detectors, software for fast processing of the gathered data, monitoring of the whole scanner, and reconstruction of the PET image. In this article, we present an analysis framework for the novel STRIP-PET scanner developed by the J-PET collaboration in the Institute of Physics of the Jagiellonian University. This software is based on the ROOT package used in many particle physics experiments.

Keywords: analysis framework; STRIP-PET

***Corresponding author: Michał Silarski,** Department of Nuclear Physics, Jagiellonian University, Reymonta 4 Kraków 30-059, Poland, E-mail: michal.silarski@uj.edu.pl

Wojciech Krzemień, Karol Stoła, Damian Trybek, Tomasz Bednarski, Piotr Białas, Eryk Czerwiński, Grzegorz Korcyl, Jakub Kowal, Tomasz Kozik, Paweł Moskal, Szymon Niedźwiecki, Marek Pałka, Monika Pawlik, Zbigniew Rudy, Piotr Salabura, Neha Gupta Sharma, Artur Słomski, Jerzy Smyrski, Adam Strzelecki, Marcin Zieliński and Natalia Zoń: Institute of Physics, Jagiellonian University, Kraków, Poland

Łukasz Kapłon: Institute of Physics, Jagiellonian University, Kraków, Poland; and Faculty of Chemistry, Jagiellonian University, Kraków, Poland

Andrzej Kochanowski and Marcin Molenda: Faculty of Chemistry, Jagiellonian University, Kraków, Poland

Paweł Kowalski, Lech Raczyński and Wojciech Wiślicki: Świerk Computing Centre, National Centre for Nuclear Research, 05-400 Otwock-Świerk, Poland

Introduction

Positron emission tomography (PET) imaging appears to be one of the most dynamically developing fields of medical sciences. Apart from the state-of-the-art detectors for annihilation γ quanta registration, PET imaging demands software for fast processing of the gathered data, monitoring of the whole scanner, and reconstruction of the PET image. Typical PET scanners are built out of hundreds of detection modules that measure both the energy and the arrival time of γ quanta. This results in a huge amount of data to be stored and processed. For novel time-of-flight (TOF)-PET devices [1–5], the number of channels to be read out could be much higher due to, for example, reading detection modules from both sides, as in the case of STRIP-PET scanner [6] being developed by the J-PET collaboration at the Institute of Physics of the Jagiellonian University.

The processing of the data collected with the PET scanner is complex and it must be performed in several steps. The process starts with the raw time-to-digital converter (TDC) and amplitude-to-digital converter (ADC) data provided by the front-end electronics, which are then combined into signals and translated to hit positions in the individual scintillator bars. Finally, the signals are matched to form the line of response (LOR), which is the line between the detected γ quanta coming from the annihilation of the positron emitted from the body of the patient. The set of LORs is then used as an input for the image reconstruction procedure. Moreover, at many stages of data processing, the adequate calibration procedure must be applied. Additional issues arise from the fact that many different algorithms and approaches are used and tested in parallel at the development phase of the prototype.

The novel TOF-PET scanner developed by the J-PET collaboration will consist of hundreds of detection modules based on long plastic scintillator strips read out from both sides by photomultipliers. Registered signals are probed in the voltage domain at several levels by a newly developed dedicated electronics working in a trigger-less mode [7, 8], which results in a large data flow. The probing will allow for reconstruction of the γ quanta interaction point based on the signal shapes. For this, special reconstruction procedures will be applied, and many possible methods can be conceived (see, e.g., [9]).

In order to address the above-mentioned needs, we have developed a flexible analysis framework that serves as a backbone system for the reconstruction algorithms and calibration procedures used during data processing and standardization of the common operations, for example, input/output process and access to the detector geometry parameters.

The general idea of the framework was adapted from the existing solutions used in the field of high-energy and nuclear physics such as ALICERoot used by the ALICE collaboration [10] or RootSorter used by ANKE and WASA collaborations [11]. However, the J-PET detection system is relatively simple compared to the full detection system used in experimental physics, such as WASA, typically composed of many subdetectors of different types; therefore, we could restrict our design to a much more lightweight architecture.

Architecture and data flow

The J-PET analysis framework is written in C++ using the object-oriented approach. It is based on the ROOT libraries [12]. The quality of the code is assured by the automatized set of unit tests. We use the BOOST unit test framework [13]. The documentation of the code is generated by Doxygen [14]. The main components of the framework are presented in Figure 1.

The JPetManager is the main part of the system. Its task is to steer the data flow and to synchronize the work of the components. It can also register JPetAnalysisModules, which will perform particular computation tasks such as calibration procedures, hit matching, and LOR reconstructions. Each JPetAnalysisModule component is a separate module that can be activated or deactivated depending on the current needs. This solution provides an easy way to incorporate new modules in the existing code. The J-Pet framework provides predefined interfaces for the input/output operation at the every level of the data processing via the JPetWriter and JPetReader components. The modules provide the common set of methods that handle operations of reading from a file and writing to a file. It also permits to save the processed objects at intermediate levels of data processing (see Figure 2).

An important part of the J-PET system is the parameter database that contains information about the geometry configurations, the DAQ setups, specific run setups, and HV settings that can be important during data reconstruction and analysis. This information is implemented as a PostgreSQL database. The J-PET framework will also

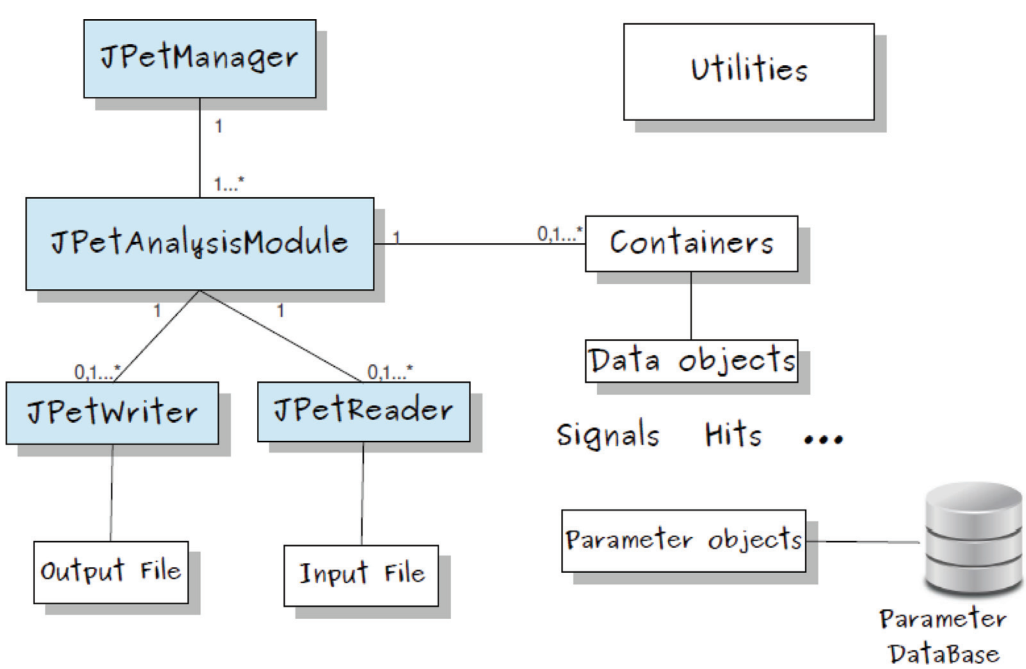

Figure 1 General architecture of the J-PET framework.
The JPetAnalysisModule could be, for example, the module for monitoring and calibration of the STRIP-PET scanner.

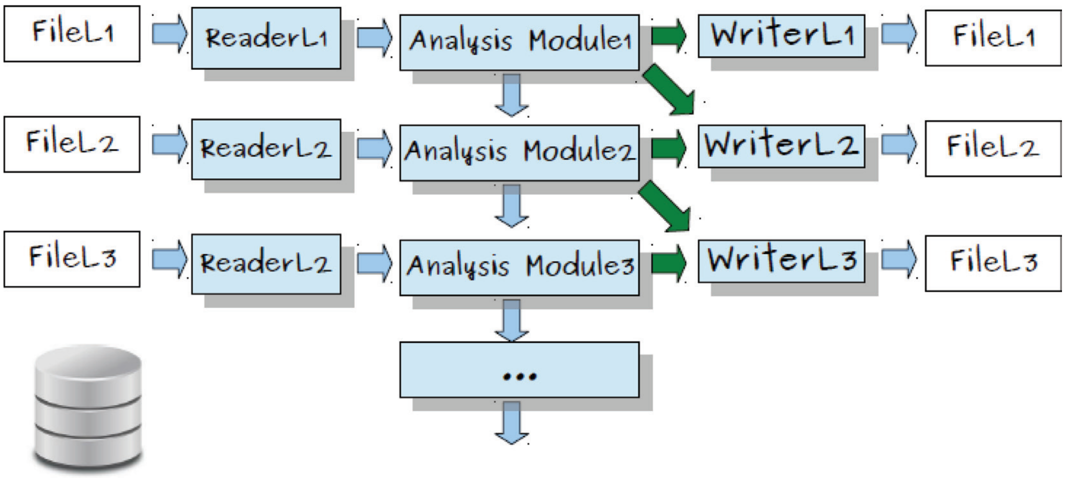

Figure 2 Schematic data flow in the reconstruction process.
Data processing is performed by the Analysis Modules, which could be, for example, calibration or hit matching modules and which send the data to the next level of the reconstruction. At every level, the intermediate results can be saved using the JPetWriter modules. Moreover, additional data can be read, if necessary, via the JPetReader interfaces. The final result of this procedure is the set of LORs, which is then used as an input to the image reconstruction algorithms.

automatize the access to the parameter database by providing the corresponding parameter data interface. The development is in progress.

Conclusions

We have developed the analysis framework for the prototype STRIP-PET detection system. This software is based on the open source package ROOT used in many experiments in particle physics. Since we are dealing with a large data flow, our software was optimized in view of computation time and computational resources utilization. The framework is being used for the offline analysis and tests, but a part of it will be also used as an online reconstruction module of the larger software system, PetController, which is developed for steering of the whole PET measurements.

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Conflict of interest statement

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