

Programs and techniques based on ROOT package for acquisition and sorting of the list mode data of the neutron detectors

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Abstract. Works on the creation, implementation and adjustment of neutron detectors in the detector groups of the neutron centers require adequate and modern hardware and software tools and techniques. As one of the useful directions we consider measurements in list mode. List-mode data acquisition based on digital electronics offers many advantages over traditional acquisition methods and is rapidly increasing in popularity. Modern digitizers employing list-mode data storage are capable to perform on-line signal processing, greatly reducing data stream sizes and increasing data throughput rates. The report describes software solutions for dealing with large volumes of list mode data from neutron detectors, which are implemented in FLNP (JINR, Dubna) and run on the IBR-2M reactor and also reactor BER-II in HZB, Berlin. Software discussed in the report is designed for position-sensitive detectors with delay line readout and for the recorded data from the gaseous proton recoil telescope for fast neutron spectrometry

1. Introduction

A detector group of a neutron center has to solve daily a variety of non-typical tasks. These tasks may occur during configuration and commissioning of detectors, search for causes of faults, or with the development of new methodologies and the preparation of new types of experiments. That is why the requirements to the software from the detector group are specific and varied. The user oriented software (i.e., software developed in response to requests of external and internal users, who carry out varied measurements using neutron spectrometers) does not cover full range of these demands.

The software requirements as specified by the detector group in Frank Laboratory of Neutron Physics (FLNP JINR, Dubna) include:

- detailed diagnostic tools (in order to receive as much information from the detector as possible),
- autonomy (stand-alone operation, independence from the experiment control systems and local database management systems, etc.),
- fast deployment,

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- flexibility (flexible configurability of parameters, easy modifications, configurable visualization tools),
- compact data formats,
- easy integration into the experiment control software (via communication components or via components which can be used autonomously),
- extensibility with respect to new equipment.

These requirements are the same for different types of detectors. Partially these demands have been realized in previous software like DeLiDAQ-1 [1] developed in collaboration with Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin (HZB, former HMI).

Recently we have started to follow such requirements in our new developments. Especially important is the first item - to get full information of measured parameters. The most complete information from the detector and about operation of the readout circuit can be extracted by list mode data. The list mode is a special measurement mode in which each event and its precise time of occurrence (timestamp) is recorded sequentially, with selected properties. List mode data can be used as a diagnostics tool to verify the performance of the detection system, but also to find time correlations between signals. This mode of the measurements corresponds to the modern trend of user oriented experimental techniques. Not only in the acquisition techniques for neutron scattering, the same trend is found in related fields [2], and at the present time a new international standard for the data format for list-mode digital data acquisition used in radiation detection and measurement is being developed by the Technical Committee 45 [3] on Nuclear Instrumentation of the International Electrotechnical Commission.

As the most suitable software for work with the event data is well known ROOT package [4] from CERN, due to its concept of the trees, designed for storing large number of same-class objects, with excellent implementation. Another reason to use this package is its compact data format. ROOT provides many other opportunities as an intensively used toolkit with complete suite of C++ classes for fitting, linear algebra, visualization of large datasets, graphical user interfaces, etc. The report describes the software solutions for the list mode data, some of which are already implemented and used by the detector professionals while others are under development. Software discussed in the report is designed for position-sensitive detectors with delay line readout and for the recorded data from the gaseous proton recoil telescope for fast neutron spectrometry [5].

2. List modes of the DeLiDAQ-1 system

DeLiDAQ-1 hardware [6] was designed for acquisition and storage of data from one- and two-coordinate multi-wire proportional chamber based position-sensitive detectors with delay line readout. A few dozens of such electronic modules with PCI interface are in use in FLNP, HZB, INP (Řež, Czech Republic), and in a number of Russian neutron centers (see overview [7] and references in [8]).

DeLiDAQ-1 detector software [1] developed on the basis of ROOT libraries [4] saves all measurement results and parameters into the file in ROOT format, at that each single measurement is saved into separate folder inside this file. Although DeLiDAQ-1 software was designed for the detector groups, this program has the remote communication modules and thus can work under control of the external experiment control program. The software offers, in addition to standard histogramming modes, interface for two types of measurements in list mode: the conventional and the packed list mode. These list modes have not been properly described in the earlier publications.

In the conventional list mode the measurement lasts during predefined time but can be interrupted by the user. The list mode can be started in the raw regime (without filtering of incoming data flow by FPGA), and in the regime with filtering (in which FPGA inspects the data stream in order to avoid incomplete events and events that do not meet the parameters of the delay line), and in both cases the mode can be with or without time-of-flight (TOF). The data flow is recorded directly to disc without any transformations. The resulting binary data file can be converted at any time by the same program into the sets of ROOT histograms and ROOT trees, which are stored in a special folder inside the measurement data file.

In the packed list mode the measurement in the TOF regime with filtering lasts infinitely until it is stopped by the user. The program converts the filtered events into a more compact binary format (32 bits per event) in real-time. When the size of the binary data file exceeds the limit of 2 GB, it is closed and a new file is started. During the measurement the user can see the evolution of the ordered histogram on the screen (typically, it is 1D TOF histogram), which is stored in the measurement folder inside ROOT data file

2.1. Internal structure of the encoded event data of DeLiDAQ-1

The internal structure of the encoded event data for these list modes (the conventional raw list mode, the conventional filtered list mode, and the packed list mode) is shown in figure 1.

Raw data. In the raw data stream, taken from the hardware, the header of three 32-bit words indicates the start of a new trigger window. Zero, one or more hits of the detector can happen within one trigger window interval. Since the system reads the information from the detector with a delay line, one detector hit includes a set of times of arrival of signals - from the anode, and from both ends of the two (or one) cathodes relative to the trigger window. Ideally single event from 2-dimensional detector contains 8 32-bit words (the ideal raw event structure is shown in figure 1).

Filtered data. In the filtered data stream, taken from the hardware, the header contains two 32-bit words, and other two words (or one word in one-dimensional case) contain 4 times of arrival of signals from both ends of cathodes relative to the anode signal. A single filtered event from 2-dimensional detector contains 4 32-bit words.

Packed list mode data. In the packed list mode case each binary data file has a textual header. The first four named sections of the header are normally filled by the information transferred by external experiment control software (like CARESS in HZB) to DeLiDAQ-1 and contain experiment specific information. The last section of the header is filled by the information about the file (path, start time of the measurement, number of file, list mode request parameters). The next four 32-bit words of the binary data file contain two timestamps: the time of saving the buffer and the time of reading from the board. These two timestamps accompany each subsequent portion of the 1024 events. After them the event list is placed, where each 32-bit word contains 9 bits for x bin number of the hit, 9 bits for y bin number, and 14 bits for TOF channel numbers (i.e. maximal resolution of the data is 512x512x16384). The ranges of X and Y channels correspond to the ranges of the main 2D histogram requested by the user.

Bits:	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Raw:	0	0	0	0	0	0	0	0	0	Counter 1							Internal information															
	Counter 2								0	FIFO							Burst number															
									0	TOF																						
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	Anode													
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	X_left													
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	X_right													
	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	Y_left													
0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	Y_right															
Filtered:	Counter								FIFO							Burst number																
									TOF																							
	1	X1										0	X2																			
	1	Y1										1	Y2																			
Packed:	TOF														Y bin number							X bin number										

Figure 1. DeLiDAQ1 event data structure for three list mode options. Bits marked as blue are used to detect the header and coordinates in the data stream.

2.2. Conversion of event data

It has already been mentioned that the program has the event data conversion tools. Besides converting to text, from the raw or filtered data the program can create a set of requested histograms, and optionally the ROOT tree with the event parameters for further analysis. The ROOT tree contains all

event-by-event information available from the system. For example, in the raw TOF case, the tree of good events (named ‘good’ tree) will have 11 components (leafs): index, TOF, x1, x2, y1, y2, anode, internal index, FIFO buffer counter, the reactor burst number, taken from hardware, the burst number defined according to TOF changes. And another tree of bad events (‘bad’ tree) contain 18 leafs: index, TOF, the last good event index, anode, x1 (or 0), x2, y1, y2, first copy of internal index, second anode (or 0), second x1 (or 0), second x2, second y1, second y2, second copy of internal index, the burst number from hardware, the burst number according to TOF changes, and FIFO buffer counter. Careful check of different combinations of these parameters can reveal different problems, starting from search of bugs in the firmware and finishing with the tasks on the optimization and the noise analysis. The ROOT Tree Browser is an excellent tool for such studies for the beginners, while the ROOT command interpreter permits a user to get picture with very sophisticated selections and cuts with only one line of code. With conversion of the filtered data we got more compact ROOT tree, because number of components (10 leafs for ‘good’ tree and no ‘bad’ tree) is less than in raw case. The table 1 illustrates the level of compactness of the discussed data formats on the real world examples taken during adjustment works with the detectors on the reactor IBR-2 in FLNP. One can see that the ROOT tree files, fully ready for plotting and express analysis, have the size not more than 2/3 from the original binary data file. The sizes of the ROOT tree files can be further reduced by increasing the compression level parameter (the program used the smallest compression ratio, that is the default value) and by the optimization of the data types of the tree leafs.

Table 1. The file sizes in bytes divided to the number of good events (i.e. number of bytes per good event in the file). Real world examples of the DeLiDAQ-1 list mode data from the detector.

Mode (all TOF):	Binary file:	ROOT tree file:
Raw (2D)	<i>(Ideal value 32)</i> 36; 55	21; 30
Filtered (2D)	16	11
Packed (2D)	4	-
Raw (1D)	<i>(Ideal value 24)</i> 64	34
Filtered (1D)	12	8

3. ELLADA program

The program ELLADA was developed for the analysis of the list mode data from the neutron spectrometer based on a proton telescope with electronic collimation of recoil protons, developed and created in the FLNP [5]. A proton telescope measures the energy of recoil protons in a gaseous medium with the use of spectra reconstruction procedure. In the FLNP telescope, the collimation occurs by the coincidence of pulses from recoil protons in several tubes of the device and, subsequently, in the sorting of experimental data using software in the chosen ranges of amplitude distributions of the signals picked off the cathodes. Although the very first prototype of the detector was equipped with electronics in the standard CAMAC, as well as the locally developed software “Lada 2010” [5] for data acquisition and processing, further steps were taken to move to the N6724 digitizer [9], produced by Caen.

For measurement of the telescope data it was decided to use the program MC2Analyzer provided by the Caen and thus store the list mode data in its binary format. The measured data (of four telescope channels - anode and three cathodes) are recorded as four files, each of which contains a timestamp value and the corresponding energy (signal amplitude) for a single measurement channel. The assignment of the program ELLADA is to assemble these independent chains of signals into a united set of events and to provide convenient interface for viewing and interactive cutting of these data using different selection criteria.

To accomplish this, the program converts the raw data into a set of four independent trees in the ROOT format, and then starts sorting intensively taking advantage of ROOT package. When sorting, ELLADA collects into one event all hits at the cathodes, which occurred close in time to a hit at the anode. The end result is also stored as a tree in the ROOT format. After sorting the program shows the various components of sorted events in form of 1D and 2D plots. The succeeding search of selection criterion is usually done by the choice of energy ranges for the various detector channels and the timing relationships between them (figure 2). Found selection criteria can be saved into the text files for further use.

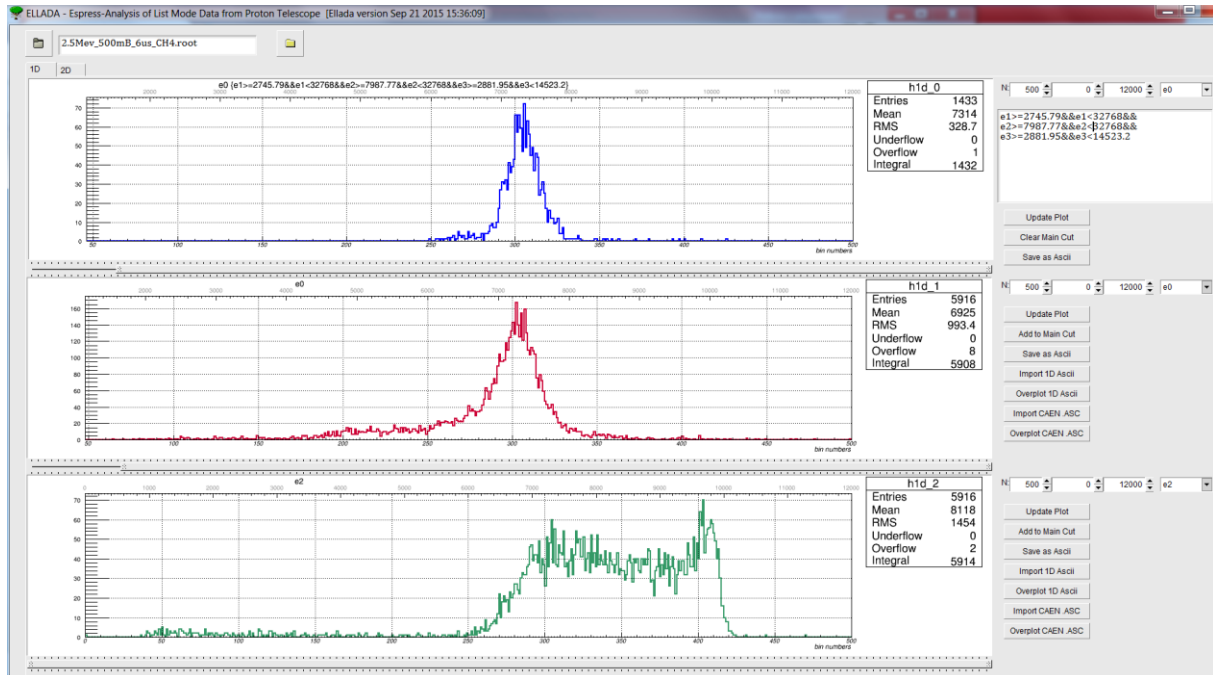


Figure 2. The main window of the user interface of the program ELLADA.

4. CaDeLin program

The program CaDeLin is being developed in the FLNP as part of the pilot project on the application of the digitizer N6730 [10] for the neutron position-sensitive detector with delay line readout. In this project we use five channels of the digitizer running DPP-PHA firmware to collect the positional signals from the detector (one anode and four cathodes). For each channel we collect the timestamp, the amplitude and the waveform (using so called mixed mode of the digitizer with the configuring of the desirable content of the stored event). The waveforms are required to us in order to increase the accuracy of calculating the position. To get the tool able to perform necessary to us measurements in mixed mode, we started to develop our own data acquisition program based on the CAENDigitizer library. After the measurements the program should build events from the chains of hits. The criterion of the hits selection is that all four hits of cathodes must happen close in time to but after the hit of anode, as well as the condition for the delay line length must be satisfied.

We decided to store the raw data directly to the ROOT tree format. The data are saved during the measurement in form of five independent trees inside a single file, while the complete events are being built out of them later. With our parameters using a fairly simple data readout circuit, we collect information without losses at input frequencies up to 130 kHz trigger rate (and up to 300 kHz when for testing purposes we have configured the measurement without reading and saving the waveform). The tests of very long measurements (a night with 70 kHz trigger rate) were successful up to the full overflow of the hard disk for data files, each time after reaching 100 GB the current file testing was

saved, and a new file was produced automatically by ROOT (our file sizes are less than 60% of the simple binary variant). We have set the parameters of the readout configuration and have measured the response of the real detector (figure 3). The works on the optimization of the stored information and the sorting algorithm are continued.

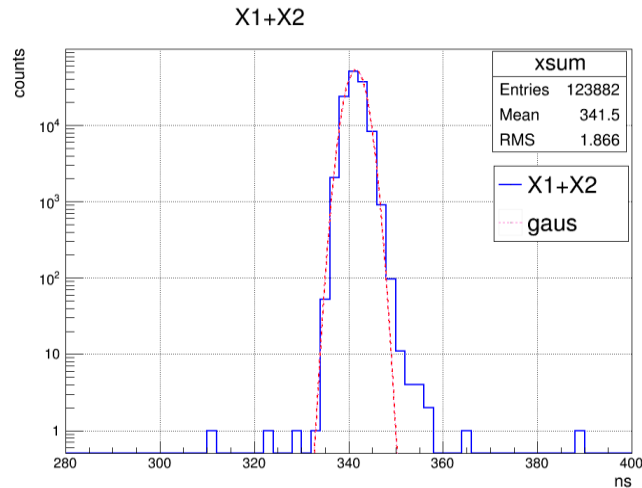


Figure 3. One of the first measurements with CaDeLin program – X1+X2 histogram of the neutron detector

5. Conclusions

We would like to draw attention to the techniques that are currently becoming more and more relevant for neutron instrumentation developments, and to offer approaches that seem to us effective, but still not often used in this field. It can be argued that the use ROOT for sorting and building of events greatly simplifies these tasks, while for further analysis of list-mode data this software is seems to be the best choice.

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References

- [1] Levchanovsky F V, Litvinenko E I, Nikiforov A S, Gebauer B, Schulz C and Wilpert T 2006 *Nucl. Instruments Methods Phys. Res. Sect. A* **569(3)** 900-4, See also 2007 *Nucl. Instruments Methods Phys. Res. Sect. A* **572** 1004
- [2] Peräjärvi K, Keightley J, Paepen J, Tengblad O, Toivonen H 2014 *Publications Office of the European Union* EUR **26715**; doi: 10.2788/88299; <http://publications.jrc.ec.europa.eu/repository/handle/JRC90741>
- [3] http://www.iec.ch/dyn/www/f?p=103:23:0:::FSP_ORG_ID,FSP_LANG_ID:1244,25
- [4] Brun R, Rademakers F 1997 *Nucl. Instrum. Meth. A* **389(1)** 81-6, See also <http://root.cern.ch>
- [5] Milkov V M, Panteleev T T, Bogdzal A, Shvetsov V N, Kutuzov S, Borzakov S B and Sedyshev P V 2012 *Physics of Particles and Nuclei Letters* **9(6)** 508-16
- [6] Levchanovski F V, Gebauer B, Litvinenko E I, Nikiforov A S, Prikhodko V I, Schulz C and Wilpert T 2004 *Nucl. Instruments Methods Phys. Res. Sect. A* **529(1-3)** 413-6
- [7] Kulikov S A, Prikhodko V I 2016 *Physics of Particles and Nuclei* **47(4)** 702-10
- [8] Litvinenko E I, Ryukhtin V, Bogdzal A A, Churakov A V, Farkas G, Hervochoes Ch, Lukas P,

Pilch J, Saroun J, Strunz P, Zhuravlev V V 2017 Upgrade of detectors of neutron instruments at Neutron Physics Laboratory in Řež *Nucl. Instruments Methods Phys. Res. A* **841** 5–11

<http://www.sciencedirect.com/science/article/pii/S0168900216310531>

(free access to the article until 4-Dec-2016)

[9] <http://www.caen.it/csite/CaenProd.jsp?parent=12&idmod=626>

[10] <http://www.caen.it/csite/CaenProd.jsp?parent=12&idmod=773>