New Data Collection Subsystem for Powder Neutron Diffractometer with Position Sensitive Detectors

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Abstract. Project INDECS (Integrated Neutron Diffraction Experiment Control System) is a newly developed software system created for the purpose of data acquisition from, and controlling of the upgraded version of the KSN-2 powder neutron diffractometer equipped with Position Sensitive Detectors. The KSN-2 neutron diffractometer (belonging to LND, DSSE, FNSPE, CTU in Prague, CZ, placed at the NRI, Řež near Prague, CZ) was recently upgraded with the possibility to contain up to three parallel linear PSDs which can be mounted on the detector arm instead of the original single counter detector. That was the motivation for the project INDECS to be started. For the actual data acquisition and initial data analysis of the raw sampled signals within the project INDECS a special modular structure called the PSD Acquisition Path (or PSDAP) was designed. Raw sampled signals from either end of the PSD are taken as the main input to the subsystem. The signals are then split into multiple events, analyzed for the position of the obtained events on the PSD, and a histogram of the diffraction events is created as the main output of this subsystem. Moreover, the PSDAP is capable of storing the raw signals either before event splitting or after, so that later the whole process of acquisition can be replayed in software, perhaps with different settings of the processing parameters or perhaps even algorithms. It can also be switched into a mode where under special conditions a correction curve specific for the given PSD can be constructed and later in normal operation it can be used to do the corrections of detected event positions to enhance the results on that particular PSD. This whole subsystem then acts as a single modular command unit (External Execution Module or EEM) within the entire system of project INDECS.

1. Introduction
The KSN-2 neutron diffractometer belongs to the Laboratory of Neutron Diffraction at the Dept. of Solid State Engineering of the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague, CZ, and it is located at one of the horizontal channels of the LVR-15 nuclear reactor at the Nuclear Research Institute in Řež near Prague, CZ. The KSN-2 has been upgraded with the possibility to allow it to switch the single counting detector head with a head containing up to three parallelly placed linear position sensitive detectors (PSDs) on the detector arm of the diffractometer (currently, the diffractometer can be changed into any of these two basic configurations: single counter or linear PSD(s)).

Introducing the linear PSDs into the KSN-2 system also required to introduce new supportive analog electronics, computer hardware and of course software as well. For this purpose the development of a new modular controlling and data collection software system began. The project is called INDECS (Integrated Neutron Diffractometer Experiment Control System) [1],

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and it is entirely based on stream communication mechanisms provided by the stream caching and multimedia stream routing libraries which were both created partially with project INDECS in mind (see [2]).

One of the main parts of project INDECS with respect to the diffractometer is the subsystem that acquires data from the detectors and does their initial processing. We call this subsystem the PSD Acquisition Path (PSDAP).

The PSDAP subsystem opens the possibility to experiment with the algorithms used to decipher the position of the event from the sampled detector signals. This algorithm can be easily replaced by a completely different one or perhaps with just slightly modified version of that algorithm, or you can just play with its various parameter settings that this algorithm may possibly have, in order to achieve the best results. This is possible due to the modular structure of the PSDAP subsystem itself.

Another feature of the PSDAP is that the raw sampled data (digitized signals coming out of either end of the linear PSDs) can be stored and read and reprocessed (or you may say "replayed") again by the INDECS system later. Of course by doing so we gain no new information about the sample, that is understandable and not really intended. But what we do gain is an option to do a comparison of the processing of the exact same raw sampled data processed by either different algorithms or different processing parameter settings within the INDECS system. That allows us to actually compare the processing algorithms or processing parameter settings with one another without the influence of the semi-random nature of the diffraction pattern caused by the semi-random nature of the neutron flux and the nature. Because even when measuring the same sample twice in a row in exactly the same experiment, you never get exactly the same raw sampled data from the detectors and so comparing these two sets of data processed with different algorithms or their parameter settings does not give us only the comparison of the algorithms or their settings themselves, but is also distorted by the randomness of the neutron events, while when comparing with the replayed data, we only get the information about the changes in processing. Of course, this feature may perhaps be more usable for the development of the data processing algorithms and their optimization, than for the actual routine measurement of the samples, but even there it may become handy from time to time. As for instance replaying of the experiments may also possibly give us the opportunity to process the previously acquired data with new algorithms developed or implemented within the INDECS project later in time.

2. PSD acquisition path
The schematic of the modular structure of the PSDAP can be seen on figure 1. There are several modules dealing with data storage, two data processing modules, one data source and one module which collects the result. The entire subsystem then hovers above the External Execution Module (EEM), which is an interface block into the rest of the INDECS system as described in [2]. All the communication with the PSDAP subsystem is done through the EEM interface via commands that this interface implements from the external point of view of system INDECS. During the initialization of the subsystem, it is literally assembled from the various modules. For some of them there can be more alternatives to choose from, depending on how many are implemented at the time.

Briefly, it works in the following way. At first the raw sampled signals are acquired by the Data Source module. Afterwards they can be sliced into multiple events in the Multi Event Separator module. From there the sampled event signals go to the Peak Analyzer module, where the position of the neutron event along the PSD is decoded. The decoded position then goes to the final Histogrammer module, where it is stored into the building histogram. The events are accompanied by their timestamps along the way, so that it would be possible to do the reconstruction in proportional time later or perhaps some statistics of the neutron distribution.
Figure 1. The schematic of the modular structure of the PSDAP with the data flow routes depicted by arrows.
in time can be procured from that if necessary.

In between these functional blocks there are optional storage blocks, which can store the signals at the adequate point of view or perhaps divert it (via the EEM interface) into another similar subsystem somewhere else if necessary.

2.1. Data source module
The data source is the interface between the PSDAP and the actual source of sampled event signals, whether these are acquired from the actual data acquisition (DAQ) card or from a file, where the signals were stored previously. The ultimate goal of this module is to prepare one sampled signal burst from each end of the PSD detector containing at least one neutron event in it, and a timestamp for that burst.

At the present time, there are two modules that fit into this slot. Since the PSD head of the KSN-2 diffractometer uses the ADLink PCI-9812 A/D converter card to obtain these signals, one of the implemented modules acquires the data from that card. The card can sample a fixed number of samples for each channel, based on a preset hardware trigger. For performance reasons a special RTLinux [3], [4] (hard-real-time sublayer of the ordinary Linux system) driver for this card was written, which is running as a real-time process and the module communicates with it via the RT-FIFO mechanism of the RTLinux. The real-time approach has its advantages, but it also has quite some disadvantages. We have no space to discuss either of them in this article, but there is a another module and driver work in progress, which would allow to use the device safely on an ordinary Linux, hopefully eliminating all the negative aspects (or at least the most severe ones) that this approach would normally have.

The second existing Data Source module does the same work, but instead of acquiring the sampled signals from the DAQ card, it rather reads them from a file, where they were stored previously during the actual experiment and, thus, allowing replaying the experiment off-line. The file to read should be of a special SDCF (Streaming Data Container Format) format. This format was specifically designed to carry streaming data, including those produced by the PSDAP.

2.2. Signal storage module
The Signal Storage module has several purposes. By far, the most important one being to store the data of raw sampled PSD signals that pass through it. From the data flow point of view within the PSDAP subsystem, the Signal Storage module is completely transparent. What is passed on to it is also passed on to the next module along the path. The storage can be done either directly to the SDCF file (the Streaming Data Container Format was specially developed for quick, yet relatively robust storage of the sampled signals and metadata from various devices, and was also partially developed with the scope of the project INDECS in mind, see [2]), or the data can be sent into the INDECS system via a virtual instruction using the EEM module interface, and then possibly stored or processed by some other part of the INDECS system.

Aside from that, the Signal Storage module can divert the entire data stream into another PSDAP for further processing, or opposite to that, it can receive such a stream from the Signal Storage module in another PSDAP and let this PSDAP continue in the processing. The communication is done via other special virtual instructions carrying the data from one PSDAP to another (usually on another computer) within the INDECS system.

Reason for this other function of the Signal Storage module is that the data acquisition may require quite a lot of CPU processing power to react quickly enough, so that some slower computers may have difficulties to catch up with the processing of the signals, when some more time-consuming algorithms are used. This allows diverting the signal processing to another computer, which may not be bound by the burden of data acquisition.
The rough data rate estimation that we are talking about here can be done based on the basic specifications of the connected devices used on the KSN-2. Given that for instance one of the used PSDs, Reuter Stokes RS-P4-1224-201 has a given averaged rate of 4200 counts per second, and that the pulse width in 0.1% of height of the semi-gaussian shape pulses produced by the used EG&G ORTEC 570 shaping amplifier is up to 63.8 µs, and that the ADLink PCI-9812 can sample at 20 MHz per channel with data stride of 16-bits per sample (though the A/D converter is actually 12-bit), that gives us a rough average estimate of about 20 MB/s data rate per one PSD. Of course, this is also very much dependent on the neutron flux, measured sample, and setting of the detector electronics, and the flow is varying in time. The actual amount of data collected, however, also depends on the length of the measurement, thus, giving about 1.2 GB/min or 70 GB/h.

Again, to be clear, the function of the Signal Storage module depends on which one of its implementations is used.

![Multiple events separated by the "Multi Event Separator" based on the original trigger level](image)

**Figure 2.** The example of a shaped signal from one end of a PSD, sampled on one hardware trigger event, separated into four shorter events using the same trigger level (1.5 V at this case) that was used to obtain this entire sample.

### 2.3. Multi event separator module

Sampling signals via a trigger based DAQ card, such as the PCI-9812, has a problem of dead times. While the internal buffer of the card is filled with a sampled event, no other events are accepted until the data have been transferred away to the computer. That may take some time (though perhaps relatively short) during which we lose whatever events the detector throws at us. Neutron events generated by the avalanche effect in a $^3$He gas filled PSD detector produce very quick and sharp peaks (with a bit longer decaying tail of course). To make them easier to detect we use the shaping amplifier (in our case it is the EG&G ORTEC 570), which shapes and broadens the peak a bit to have about 3 to 64 µs. You can see an example of such a shaped signal on figure 2.

Since the card can sample at least few hundreds of s, we can use it to our advantage and sample as much as possible on one event and subdivide the sample into multiple shorter events (as seen on figure 2) to improve the number of detected neutrons. This is the job of the Multi Event Separator module. So far, we have only one instance of this module implemented that uses a simple trigger level separation.
2.4. Peak analyzer and histogrammer modules

The Peak Analyzer module evaluates the sampled event signals and decodes the position of appropriate neutron events along the PSD, while using the preloaded compensation curve to compensate for nonlinearities of the detector. This operation produces one simple number determining the linear position and that is then passed to the Histogrammer module, which stores it into a histogram of such events and allows retrieving the resulting histogram by other parts of the INDECS system as a result of the diffraction experiment for further evaluation.

Currently there is just one implementation of the Peak Analyzer determining the position from the height of the peaks on either side of the PSD, with the use of given PSD specifications and its current position with respect to the sample and a compensation curve for the specific PSD profile corrections.

There is currently also just one simple implementation of the Histogrammer, which has a number of bins determined by the experiment setup (length and spatial resolution of the PSD and the area to be covered by the PSD arm movement). The events are counted based on the position of the individual events produced by the peak analyzer module and current detector arm position as obtained by the axis control subsystem of the INDECS project.

The events positions can be stored or inspected by the Event Storage module in between these two modules, but at the present time it is only used for debugging purposes.

3. Conclusions

While most of the essential parts of the PSDAP subsystem mentioned in this text are more or less finished and tested with artificial testing inputs, the current development of the project INDECS for the KSN-2 neutron diffractometer is mainly focused on creating the ordinary Linux port of the PCI-9812 driver based on the Q-Buf Kernel Stream Engine technology (see [2]) to get it as close to the behaviour of the now hard to operate on modern computers real-time (RTLinux) variant of the driver written in the past and used for the initial tests of the PSDs data output, before the core of the project INDECS was implemented. When this driver is finished the PCI-9812 data source module can then be used to actually obtain the data directly from the PSD detectors into the PSDAP subsystem. Currently the modules of the subsystem can only be fed by artificial or presampled data, which is good enough for the initial tests of the PSDAP modules, to determine their functionality and for their debugging purposes, but not enough for testing the actual properties that the PSDAP subsystem of the INDECS system shall have when really connected and fed from the PSDs of the KSN-2 in real time to show some real experimental results. That is why the development of the new PCI-9812 driver and several other supportive parts of the INDECS project are so important now.

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