Development of a common trigger-less streaming-readout data acquisition system for Grand RAIDEN and MARQ spectrometer

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A magnetic spectrograph, Grand Raiden[1], has the world-best resolving power and the great advantage for the measurement of the zero-degree scattering. Thanks to the upgrade of the AVF cyclotron, the expected beam intensity and the resulting trigger rate become higher. This opens the opportunity to challenge the rare-event measurements such as two- or multi-nucleon transfer, exotic charge exchange reactions and multi-particle coincidence measurement. In such measurements, the hardware trigger is difficult to produce and the single-rate becomes high when the enough statistics is required. For example, the two-nucleon transfer reactions, (^{4}He,^{6}He) (E585) and (^{4}He,^{6}Li) (Honor seminar) at an incident energy of 100 MeV, to deduce respectively the static polarizabilities of the two-neutron pair and the proton-neutron pair fields, suffer from the existence of large amount of light ions higher than 100 kcps at the final focal plane. The traditional trigger signals are produced using the light output of plastic scintillator but it is difficult to reduce the triggers due to the light ions even by the combination of charge and timing information. Then the data acquisition system is requested to accumulate the data with more than 100 kcps triggers.

In order to acquire all the data associated with more than 10^5 particles per second, a total throughput of 230 Mbps ($\sim$30 MB/s) to record at least 12 hits in VDCs and four hits in PSs are recorded for each particle and more than 2 MHz RF timing. The throughput itself is not high and basically can be covered by the conventional trigger-type VME-based readout system. However, the repetition rate is too high to achieve the low dead time.

In the trigger-type readout system, an accepted-trigger rate $N_{\rm acc}$ for a requested-trigger rate $N_{\rm req}$ with a dead time of $t_{\rm busy}$ is estimated as $N_{\rm acc} = N_{\rm req}/(1 + N_{\rm req}t_{\rm busy})$. Assuming the typical dead time of 14 μs, which is estimated by using the DMA transfer of 36 32-bit words including leading and trailing edge from V1X90 TDC modules products of CAEN Co. Ltd., presently the operation point is chosen so that the dead time ratio is about 10% corresponding to less than 10 kcps, which is far from the requirement by the measurements mentioned above.

Similar, or more severe situation happens in the measurement at J-PARC using a spectrometer under construction by E50 collaboration, named MARQ, which will be located at so-called π-20 beamline after the extension of the hadron hall. In this experiment, more than 10 Gbps data rate is expected and the hardware trigger is hardly produced again. In order to overcome this situation, a data-streaming-type TDC[2] and a prototype of a streaming readout data acquisition software[3] have been proposed. In this scheme, the readout throughput depends on the bandwidth between the frontend electronics (FEE) and the readout interface, *i.e.* ethernet in this case, and on the data processing time including intra-network communication. This scheme is originally developed for the experiment at J-PARC but is applicable for the other experiments, of course, at RCNP. Such a streaming readout system has much attraction among the world.

The data acquisition infrastructure division in RCNP, newly established in 2022, has initiated together with E-SYS (IPNS, KEK), Data System Team (RNC), CNS (Tokyo), ELPH (Tohoku), a collaborative development group called SPADI Alliance (signal processing and data acquisition infrastructure alliance) [4] for developing a common-use or standardization of the trigger-less streaming readout system and has conducted the first implementation of this system in physics experiments E585 and Honor Seminar in July, 2023.

In these experiments, scaler process, decimator process and event builder process are newly implemented in the NestDAQ software framework. The scaler process counts the number of hits in individual channels to define the single rate of each detector. The decimator process provides unbiased data set by selecting a part of time frames. The event builder process slices the time frames with a given time period respected to a given reference signal. The topology of the process network is shown in Fig. 1. Eight AMANEQs equipped with

1-ns-LSB TDC receives the signals from the amplifier shaping discriminator card attached to the vertical drift chambers (VDCs). One AMANEQ [5] equipped with 1-ps-LSB TDC received the signals from the charge-to-time converter module [6] which accumulates the electric signal from the photomultiplier tubes attached to the plastic scintillators (PSs). All the AMANEQs are frequency-aligned to the reference clock distributed by CDD-OPT via the MIKUMARI protocols [7]. Samplers collects all the data from AMANEQs, sub-time-frame builders pack some heartbeat frames, time-frame builders merges the corresponding sub-time frames which have same frame id into time frame, and then the event builders slices the time frame to define the event where at least one signals in the reference detector is detected.

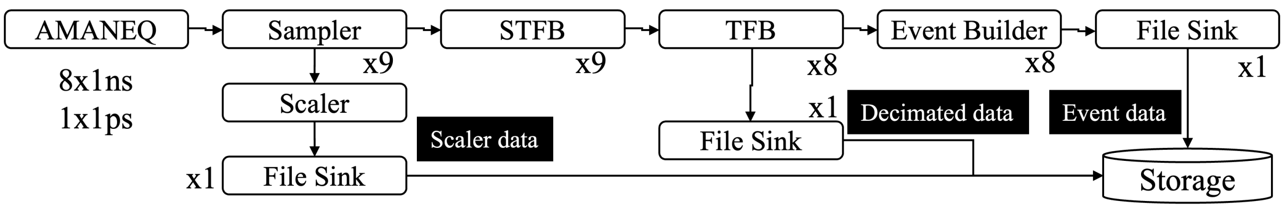

Figure 1:

Here we introduce the result from (^{4}He,^{6}Li) reaction measurement. The analysis of the decimated time frame gives the total throughput of ∼300 Mbps and the particle rate more than 100 kcps. Although the particle identification using the signal from PSs is difficult as expected, the time over threshold of the VDC outputs gives the clear particle identification. The signal-to-noise ratio is less than 0.1%. This result shows that the experiments with higher particle rate can be performed with the Grand RAIDEN with the trigger-less streaming data acquisition system.

However, the data rate is not so small to prepare the enough size of data storage over the future and the analysis speed becomes slow when the data size is large. Next step is to prepare the online filtering, for example, to reject the light-ion data by using the time-over-threshold in VDC. Such a filter is under development although the basic filter is already tested.

The same implementation and the upgraded firmware and corresponding implementation have been tested in J-PARC T103 experiment and worked well. The details will appear in the future manuscript.

In summary, the new trigger-less streaming readout data acquisition system has been applied to the physics experiment for the first time in RCNP and the more than 100 kcps trigger-equivalent data acquisition is realized. The same system works also in J-PARC experiment. This is the first step of the standardization of the data acquisition system. The detailed description of the implemented trigger-less streaming-readout data acquisition system will appear in Ref. [8]

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