LabVIEW Data Acquisition for NE213 Neutron Detector

Dhevan Gangadharan

Office of Science, Student Undergraduate Laboratory Internship (SULI)

University of California, Davis

Stanford Linear Accelerator Center

Menlo Park, California

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ABSTRACT

LabVIEW DAQ for NE213 Neutron Detector. MOHAMMED AL-ADEEB (University of California, Berkeley, Berkeley, CA 94720) DHEVAN GANGADHARAN (University of California, Davis, Davis, CA 95616) SAYED ROKNI (Stanford Linear Accelerator Center, Menlo Park, CA 94025).

A neutron spectroscopy system based on a NE213 liquid scintillation detector at the Stanford Linear Accelerator Center measures neutron energies from a few MeV up to 800 MeV. The neutrons are produced from the electron beam and target interactions. The NE 213 scintillator, coupled with a Photomultiplier Tube (PMT), detects and converts radiation into electric pulses for signal processing. Signals are processed through Nuclear Instrument Modules (NIM) and Computer Automated Measurement and Control (CAMAC) modules. The processed pulses are then fed into a CAMAC analog to digital converter module (ADC). The ADC classifies the incoming analog pulses into one of 2048 digital channels. Data acquisition (DAQ) software based on LabVIEW version 7.0 acquires and organizes data from the CAMAC ADC. The DAQ system presents a spectrum showing a relationship between pulse events and respective charge (digital channel number). Various photon sources, such as Co-60, Y-88, and AmBe-241, are used to calibrate the NE213 detector. For each source, a Compton edge and reference energy in MeV [1] is obtained, resulting in a calibration curve. This project is focused on the development of a DAQ system and control setup to collect and process information from a NE213 liquid scintillation detector. A manual is also created to document the process of the development and interpretation of the LabVIEW-based DAQ system.

INTRODUCTION

Emission of neutrons at the Stanford Linear Accelerator Center (SLAC) is a result of the electron beam interactions with targets. Spectroscopy systems are used to measure neutron spectra for a range of a few MeV to 800 MeV [2]. Project entails the creation of a data acquisition system to process data at a much higher rate and from multiple detectors.

The NE213 liquid scintillator is sensitive to both photon and neutron radiation. The liquid is composed of hydrocarbon groups. Photon radiation interacts with the detector either by Compton Scattering, the Photoelectric Effect, or absorption. Compton scattering is the predominant occurrence in NE213. Scattering excites electrons into higher energy states. The atoms then become unstable, causing electrons to drop back to their stable energy state. The electron's lost energy results in photon emission. Neutron radiation acts in a more indirect method. Incoming neutrons bombard the nuclei of the hydrogen or carbon, ejecting a proton. The proton may either excite orbiting electrons or decelerate causing photon emission [3]. Both types of radiation result in the emission of photons.

Emitted photons are however too weak for detection. A PMT as well as an amplifier is attached to the end of the scintillator to strengthen the signal. In the PMT, a photocathode wall converts photon energy to electron energy. Electrons then multiply through a series of dynodes, resulting into a strong pulse [4].

NIM and CAMAC systems process these pulses in preparation for DAQ by a PC. It is the job of the NIM system to generate Gates (square pulses) when triggered by pulses from the PMT. The CAMAC system's most important task is the integration of pulses from the PMT. The gates generated by the NIM system designate the start and stop times of pulse integration. The ADC module in the CAMAC crate integrates the pulses to convert the analog signals into digital

signals/channels [5]. Two methods have been developed to acquire the information from the ADC. They are the Look-At-Me (LAM) and Digital I/O Trigger methods. The LAM method employs the use of the LAM register. The LAM register is contained within the CAMAC crate controller, which traffics the flow of data to and from the Computer. The ADC sends out a LAM when it has finished digitizing information and is in need of attention. This method looks for this LAM at a manually pre-set frequency. The second method, Digital I/O Trigger, a more computer automated system. It uses a digital I/O board to tell the LabVIEW based DAQ program when and when not to read data from the ADC. Unlike the LAM method, the Digital I/O trigger method does not have a pre-set frequency to read data from the ADC; rather it reads from the ADC whenever the PC has finished processing the previous event.

The NE213 detector is calibrated by various photon sources such as Cobalt-60, Yttrium-88, and AmBe-241. AmBe is also a neutron source, the calibration curve represents both photon and neutron energies. The calibration allows for a correlation between radiation energy and NE213 energy absorption.

A manual is also developed to document the techniques and background information used in achieving the desired results. The PC used for experimentation runs on a Pentium II processor at 600MHz with 130KB RAM. It runs a Windows NT operating system.

MATERIALS AND METHODS

Signal processing and LabVIEW data acquisition are the two major compositions of the project. Signal processing is done via CAMAC and NIM modules. The most important part of signal processing is gate generation. The idea behind the gate is providing the CAMAC ADC with the proper period of time for pulse integration, which is specified by gate width. The ADC

converts analog pulses into digital signals using charge integration. The integrated charge is classified into one of 2048 channels. The LabVIEW DAQ program is responsible for acquiring and analyzing this data from the CAMAC ADC.

The NE213 liquid scintillator scintillates upon incident radiation. Generated photons by the NE213 are converted into electronic pulses through a PMT. -1000 Volts is applied to the PMT. The electronic pulses are fed into an amplifier of gain 10. The signal from the amplifier is routed to both a LeCroy 623B Octal NIM Discriminator and a LeCroy 2249W ADC. The discriminator triggers off of incoming pulses and creates gates. The gate width is set at 120 nsec to assure that the scintillator's pulse is fully represented. A threshold is adjusted on the discriminator to exclude noise; this parameter is set to 0.0302 Volts. The gate is a standard NIM pulse, -0.7 Volts [5]. Another standard often dealt with in control circuitry is the 3- 5 Volt TTL signal. One must take care not to cross NIM and TTL signals.

From this point forward, the circuitry is characteristic to both DAQ methods, LAM and Digital I/O Trigger. The LAM system hires the LAM register as the determining factor to perform the next read; the other system acquaints the Digital I/O Board to control the traffic of information, defining when the ADC is ready with new information, synchronizing data flow.

Look-At-Me System

One of the outputs of the discriminator is sent to a CAMAC LeCroy 2323 Duel Gate Generator. The gate generator is manually preset to generate a one-millisecond gate each time a signal or trigger comes in. This gate is sent back into the discriminator's inhibit terminal. The inhibit terminal functions to veto all output signals from the discriminator while an inhibit signal exists. Thus, in our setup the discriminator is inhibited for one-millisecond after the discriminator detects an event. This is to allow time for the ADC to digitize the existing analog

signals at its terminals. This period of inhibition is also accounting for other module delays, wire delays, and computer processing time. The Circuit diagram is shown in figure 1.

Also note that the pulses routed to the ADC from the amplifier are delayed by 20 nsec. This is to assure that the pulse arrives at the terminals of the ADC within 8nsec of the start of the gate pulse. The 8nsec accounts for the internal delays of the ADC itself. The ADC is prepared to start digitizing the signal 8nsec after the arrival of the gate [5].

Digital I/O Trigger System

The Digital I/O Trigger method, although more complicated, is a much more beautiful system by virtue of its synchronization and computer automation. The circuitry setup continues as follows. From the discriminator, a gate flows into a Phillips Scientific Quad Four-Fold Logic Unit model 754 set to operate as a Fan-out module. A Fan-out reproduces multiple of the same signal. Of these signals, one is routed to the LeCroy 2323 Gate Generator, set to latch mode. In latch mode the module is triggered through the start terminal and produces high signals until it is shut off through a stop signal in the stop terminal. One of the outputs of this Gate Generator is routed to the veto terminal of the Fan-out unit. The veto terminal functions exactly like the inhibit terminal of the discriminator. If the latch is set, the veto exists, and according to the circuitry in Figure 2, gates no longer flow to the ADC. The gates remain vetoed until the latch is removed. The latch is removed by the program through the Digital I/O Board to allow the next event to come into the circuitry. The Digital I/O Board interfaces the PC to the control setup. It is a terminal of communication, empowering the program to set conditions on the control setup.

Event-by-Event processing and the Digital I/O Trigger

The first pulse from the scintillator latches the Gate Generator, thereby vetoing the fan-out. Meanwhile a gate has flown through the discriminators to the ADC. The Digital I/O Board looks to see if the Gate Generator is latched or not. If latched, an event has obviously been into the circuitry and the ADC is ready to be read. The intrinsic delays of the circuitry and PC allow for the ADC's digitizing time. After an event is read into the PC, the Digital I/O Board clears the latch of the Gate Generator allowing for the next event to come into the circuitry. The circuit diagram is shown of figure 2.

LabVIEW Data Acquisition

The LabVIEW data acquisition program begins performing a set algorithm of initializations on the CAMAC GPIB crate controller and the CAMAC system. Figure 3 shows the programmers view of the GPIB being initialized through a sub VI (sub-program). The sub VI is provided in the LabVIEW DAQ library. A CAMAC crate controller clear operation and an enable LAM operation is performed at the beginning of the program as well. To clear the CAMAC crate controller three parameters are specified: the slot number, the sub-address, and the function code (n, a, f) [5]. The slot number refers to the module's station number in the CAMAC crate. The CAMAC crate has 25 slots; slots 24-25 are reserved for the crate controller, leaving 23 slots for other modules. The sub-address refers to a particular connection within a particular module. The function code indicates what kind of operation is to be performed (read, write, or control command). All three parameters are shown in Figure 4 in the CAMAC clear operation.

After configurations and initializations, the program then proceeds to open a file and appends headers. After that, data collection begins. Either the LAM or the Digital I/O trigger method is used.

LAM Method

Once the ADC has finished digitizing one event it sends a LAM out to the crate controller. The LAM from the ADC is stored within the LAM Request Register in the crate controller. The Register is composed of 24 bits. Every station in the crate corresponds to a bit. There are 24 bits for 24 slots, although the crate controller also occupies station 24. The process in Figure 5 looks for the bit that corresponds to the location of the ADC, finding out whether it is has a LAM or not. If the bit is off then the process is repeated until a LAM is set. If, however, a LAM is not set after 20 loops, the crate controller has “hung up” and is in need of a “jump start.” The problem of “hanging up” only occurs with the LAM method, and is caused by improper vetoing of gates. If the bit is found to be on, however, the loop is broken and data is read from the ADC. The read is executed using the slot #, sub-address, and function code (n, a, f). To read from the crate controller: $n = 30$, $a = 0$, and $f = 2$ [5]. A histogram is then created showing the number of events against ADC channel number. The histogram is updated with every collected event.

Digital I/O trigger method

With the Digital I/O trigger method, events are detected not through a LAM but through the latching of the Gate Generator. The Gate Generator latches when an event comes into the circuitry as explained before. Figure 6 shows the loop that searches for an event or trigger in our circuitry. The advantage of using this method in search for events lies in the delay time of each loop. Searching for a LAM takes much longer than searching for a trigger.

Data is taken from the three sources: Co-60, AmBe-241, and Y-88. The affect of background radiation is removed from the data set of each source. Figure 7 is the result of a radiation reading from a Co-60 (1mrem) source without the affects of background radiation. The

hump corresponding to the largest number of counts is known as the Compton Peak. The channel under the Compton Peak represents the most *likely* energy of radiation. The region just to the lower right to the Compton Peak is referred to as the Compton Edge. The Compton Edge is unique to every source. The Compton Edge is calculated by multiplying the number of detected particles at the Compton Peak by the Compton Edge Factor [3].

Importance of taking the Compton edge

It was found experimentally that the peak of a spectra coming from the NE213 liquid scintillator, corresponding to the highest number of counts, does not accurately reflect the source present. Through erroneous processes in the scintillator, a source may seem to have more counts at the Compton peak than there actually are. The amount of absorbed radiation in the scintillator presents one of a few erroneous processes that lead to need of a Compton Edge Factor. The Compton Edge Factor accounts for these processes and yields a much truer display of the energy of radiation.

The Compton Edge Factor is tabulated for the different sources in the table below. The Compton Edge Factors are found experimentally.

Source	Compton Edge Factor	Source Energy [MeVee]
²⁴¹ AmBe	0.664	4.2
⁸⁸ Y	0.642	1.61
⁶⁰ Co	0.303	1.15

RESULTS

The Digital I/O Trigger system works much more efficiently than the LAM system. The LAM system collects events from a Co-60 source at 131 particles per second (pps) while the Digital I/O Trigger collects at 470 pps. Depending on the size and type of source present, the total particles recorded per second vary.

One of the limiting factors on the speed of the system is the internal delays of the modules and also the speed of the PC. If a faster PC is applied to this system the number of particles recorded per unit time will surely increase.

The LAM system has a problem of freezing at random intervals of data gathering. A “jump-start” feature is developed to break out of the frozen or “hung up” system and continue data collection. The “hang up” is caused by improper timing of inhibit and read commands. The system freezes at points in which an overwhelming flow of data is directed to the ADC. To read data from the ADC at such a critical moment freezes the ADC. The jump-start feature reinitializes the registers of the CAMAC system. The Digital I/O Trigger system does not this problem. It is designed to traffic the flow of data so that the ADC never experiences a “hang up.”

The data acquisition systems, whether LAM or Digital I/O Trigger, create spectra of counts vs. ADC channel #. The spectra for Cobalt-60, Yttrium-88, and AmBe-241 are plotted with two curves in figures 8-10. The pink curves represent the sources spectrum including affects of background radiation. The blue curves exclusively show spectra of the source. A long sample of background radiation is taken to subtract its effects off of the source and obtain the blue curve.

The calibration curve for the NE213 liquid scintillator is found using the following parameters: –1000 Volts applied to the PMT, and an amplifier of gain 10. If these parameters are modified, a different calibration curve will result. Therefore, the calibration curve in Figure 11 is only valid for those parameters. The plot is derived from the three photon sources. The linear regression of the curve below is 0.9999. The curve is nearly linear.

STATISTICAL UNCERTAINTY

The error analysis and calibration curves were based on one run from each source, and therefore our results are subject to some statistical uncertainty. Radiation is a random yet well known process. Even though a sample may radiate at a slightly different rate from day to day, it does have a well known average. This is the basis for the legitimacy of our results.

From the results in figures 8-10 it is evident that every ADC channel corresponds to a particular number of counts. The counts corresponding to every channel has some statistical uncertainty. For randomly distributed events, the uncertainty sigma is always calculated to be the square root of the number of counts [6]. In addition to this, propagation of errors must be accounted for when background radiation is subtracted off of the source. The resulting statistical uncertainty pertaining to the source is the square root of the sum of the squares of the uncertainties of the source and the background radiation.

$$\sigma_{\text{source}} = \sqrt{(\sigma_{\text{background}}^2 + \sigma_{\text{source with background}}^2)}$$
$$\sigma \equiv \sqrt{\text{counts}}$$

This is done for each channel of the ADC, since each channel has its own number of counts. The uncertainty in each channel's counts also shows up as an uncertainty in Compton Edge, which affects our calibration curve. The calibration curve in Figure 12 includes error bars.

DISCUSSION AND CONCLUSION

The calibration curve plots energy from 0 to 4.5 MeV. Using this equation, the neutron spectroscopy system is capable to map energy levels from a few MeV to 800 MeV. The spectroscopy system is sensitive to photons and neutrons, although our primary concerns are neutron sources.

The calibration curve resulted nicely with an R^2 value of 0.9999. This reflects the quality of the data acquisition system, the circuitry and the scintillation detector. The calibration curve gives a means of correlating the amount of absorbed radiation to the incident radiation energy. Placing this data acquisition system in a particular environment, one may determine the radioactive energy existing

The data acquisition system took two routes, one employs the Look-At-Me register and the other employs the Digital Input/Output Board to traffic data flow through the circuitry. The Digital I/O Trigger method typically runs four times faster than the LAM method. The Digital I/O Trigger is also more stable. This project is one phase of larger experiments. In the future, the calibration curve will also include cosmic muons; this will increase the visible range of the curve drastically. Ongoing phases are implementing a system, which can differentiate energies of photons and neutrons.

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FIGURES

Circuit Diagram – Look-At-Me

Figure 1. Circuit Diagram for the LAM method

Circuit Diagram - Digital I/O Trigger

Figure 2. Circuitry for the Digital I/O trigger method.

Figure 3. GPIB initialization

Figure 4. Clearing the CAMAC registers

Figure 5. Searching the LAM request register for the presence of a LAM in the 21st slot or bit.

Figure 6. looping/waiting for a trigger/event.

Figure 7. Spectrum showing counts vs. ADC channel number for Co-60 (excludes background radiation).

Figure 8. Spectrum of Co-60.

Figure 9. Spectrum of Y-88.

Figure 10. Spectrum of AmBe.

Figure 11. Calibration curve for the NE213 using all three sources.

Figure 12. Calibration curve for NE213 with error bars.