Extraction of Time and energy data from a digital pulse processor *

Extended Abstract†

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ABSTRACT

A brief overview of the importance of time and energy measurements in the field of particle physics. The uncertainty given by the Heisenberg uncertainty principle to the measurements being made. A discussion about the software which will be developed to allow for the accurate extraction of time and energy data as well as the analysis tools which will be developed to process this data. Finally resulting in an experiment at iThemba Labs which this software will be crucial in the verification of the detector process being developed.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Data Acquisition* → Analysis;

KEYWORDS

Digital Pulse Processors, Data Acquisition, Spectrum Analysis, digital partial detector processing.

1 INTRODUCTION

C.W Fabjan defines particle detectors as "Particle detectors are instruments used to measure the kinematic properties of particles and quanta." (Fabjan, 1994) The kinematic properties are mass, position velocity and acceleration. These properties can be derived from the characteristics of detection events. Namely the energy of a particle and the time at which an event occurs.

Once an event has occurred it is registered in the Data Acquisition (DAQ) system and stored on a computer via an interface program. For this use case a software package called Paass-lc (Paulauskas, 2018) will be used as it provides both acquisition and analysis frameworks. However, this package is not designed for the specific use case of time and energy signal retrieval from multiple detectors simultaneously to register individual events. But rather it is designed in a general manner that allows it to be extended by a researcher to accommodate for their specific use case.

My Honors project will be the development of a tool using the paass-lc frameworks to retrieve time stamped energy events from the DAQ system. The data retrieved will allow for the time calibration of the particle detectors. During the decay of various radioactive isotopes, a gamma ray pair is produced which are then emitted in opposite directions. this time calibration is essential in the measurement of these decay events, as it allows for the measurement of the position of the decayed particle with respect to the Heisenberg uncertainty principle. And this position with coupled with the energy of the emitted gamma rays can be used to determine the various other kinematic properties of the particle.

2 COMPUTATIONAL DETAILS

2.1 Time Calibration

To calibrate the detectors a radioactive source is placed a predetermined distance form either apposing detector. Then by measuring the precise time of arrival of the gamma ray emitted during a decay it is possible using newtons equations of motion to calibrate the detector in time with respect to these positions.

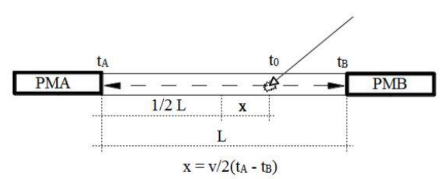

Fig (1)

If the time of an event at Detector A occurs at t_A and the event at Detector B occurs at t_B it is possible to determine the position of the particle between these detectors using Newtons Equations of motion.

This which gives the Equation displayed in Fig (1):

$$x = \frac{v}{2}\ (t_A - t_B) \qquad \text{Eq (1)}$$

2.2 Energy Calibration

The energy calibration is accomplished by using a radiation point source whose emitted energy spectrum is well defined.

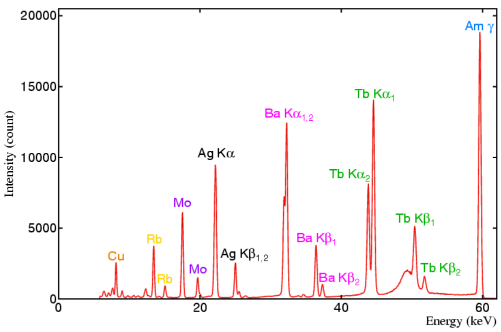

Fig (2)

	$K\alpha_2$	$K\alpha_1$	$K\beta_1$	$K\beta_2$
Cu	8.042 keV			
	(1.54178 Å)			
Rb	13.377 keV		14.963 keV	
	(0.92688 Å)		(0.82863 Å)	
Mo	17.446 keV		19.610 keV	
	(0.71069 Å)		(0.63225 Å)	
Ag	22.108 keV		24.946 keV	25.459 keV
	(0.56083 Å)		(0.49701 Å)	(0.48701 Å)
Ba	31.820 keV	32.197 keV	36.382 keV	37.261 keV
	(0.38965 Å)	(0.38509 Å)	(0.34079 Å)	(0.33275 Å)
Tb	43.745 keV	44.478 keV	50.399 keV	51.747 keV
	(0.28343 Å)	(0.27876 Å)	(0.24601 Å)	(0.23960 Å)

Table (1)

Fig (2) (for explanatory purposes) is a great example of a calibration spectrum. Using the values from (Prince, 2004) represented in Table (1) the energy in keV will need to be mapped to the channel number listed on the x-axis of Fig (2). This is accomplished by plotting the graph of channel number to energy. Then finding the line of best fit for this data. As the channel numbers n of a detector are approximately proportional to the energy E being measured the points on the graph will follow a quadratic relationship at high energies. The calibration step is reduced to the process of solving for the constants: a, b, c in the equation

$$E(n) = a + bn + cn^2 \qquad \text{Eq (2)}$$

This can be accomplished using the method of chai-square defined in (Siegal, 2016).

$$x^2 = \sum_{n_i}^{n_f} \left(\frac{E(n) - Expected(n)}{\sqrt{Expected(n)}} \right) \qquad \text{Eq (3)}$$

Where n_i is the first channel number, n_f is the final channel number, E(n) is the energy predicted by Eq (2), Expected(n) is the expected energy at the channel number n.

Eq (3) is used by varying the constants a, b, and c until the value produced by chi-shared is the closest to 1, making this an optimization problem. Various optimization algorithms will be implemented and tested including Global Search, Multi Start, and Pattern search. They will be evaluated, and the optimal solution will be used in the project.

3 FEATURES AND METHOD

3.1 TOOL TO BE BUILT

The resulting system will be built upon the paass-lc tool. It will expand on both the acquisition and analytical frameworks provided by the tool.

- It will use Paass-lc as a data recording program to interface with the DAQ.
- The program will then calibrate the energy spectrum incident on the detectors using the method of chi-squares in Eq (3).
- The subsequent events incident on the calibrated energy channel will then be recorded with its precise time stamp.
- Using this time stamp only the events occurring with in a specific time frame threshold will be recorded.
- Using Eq (1) the precise position of the events will be determined, and the various other kinematic properties will be determined from the position.
- Data will be recorded in a MySQL database cluster using the apache Kafka framework to build streaming pipelines to connect the storage infrastructure together.

Initially this system will be built as a processer within the paass-lc tool and then will be developed into a standalone python library for ease of use and in the future more advanced analysis tools can be built on top of it more easily.

3.2 DEVELOPMENT CYCLE AND GOALS

Even though there is a clear and well-defined problem which needs to be developed, as with any software project there is still space for the requirement to change and as such an agile approach towards the software engineering cycle will be followed. With regular scrum meetings with my mentor as we discuss the changing nature of the project as we learn more about the reverse engineering of the paass-lc tool.

4 APPLCATIONS AND CONCLUSION

4.1 NUCLEAR MEDICINE

Positron emission tomography (PET) is a powerful and non-invasive method of imaging physiological processes occurring in the body. The time of flight techniques spoken about in this paper are already being used in modern PET scanners as, "In the newer generation of PET detectors the resolution of the tomographic image is improved by determination of the annihilation point along the line-of-response." (Silarski, 2013) This method is powerful as it reduces the noise along the line-of-response. This noise reduction occurs as the double event from the single particle decay reduces background noise as events recorded along the line-of-response which do not occur within a certain time frame are ignored, thus reducing the false positives caused by background radiation.

4.2 CONCLUSION

The tool that I will be developing has numerous applications in the fields of not only particle physics but also Nuclear medicine. This tool will be developed throughout the year and will be tested, and its operation be verified in an experiment run at iThemba labs later this year. It will consist of the modification of an existing widely used scientific tool. It consists of interfacing with embedded systems, and FPGA's. Various modern Optimization Algorithms will be implemented and studied throughout this development cycle. The expanded system will also touch on the fields of cluster computing for storage, and high through put data management for the important step of data storage.

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