A pulse pile-up correction method for high-rate radiation spectroscopy

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Abstract

Pulse pile-up effect degrades the energy information of radiation detection systems. Numerical methods can be employed to restore the pulse height information. This study investigates the feasibility of a pulse tail extrapolation approach for estimating the true pulse heights for energy spectrum calculation. Instead of using the conventional nonlinear least squares method, a non-iterative method based on integration is proposed and shown to be a promising choice for fast applications.

Keywords: Pile-up correction, Pulse tail extrapolation, Radiation Spectroscopy.

Introduction

Radiation spectroscopy at high count-rates suffers from pulse pile-up (overlapping) effects, which is a result of two main factors: a) the random nature of particle emission from radiation sources, which means events of any time distance can occur, and b) the finite length attributable to each pulse, which is the time the detection system is busy with the processes of charge generation and collection after a particle interacts with the radiation detector. In addition to the detector, other electronic components of a spectroscopy system may also contribute to pulse length [1].

Pile-up effect disturbs the energy information of the detection system. Most remarkable strategies proposed to deal with this problem are: a) pulse shortening (shaping) to reduce the pile-up probability, b) pile-up rejection and c) pile-up correction (pulse information recovery) [2]. The latter case requires quite more computational resources, available nowadays by modern digital processing modules.

Various innovative pile-up correction methods can be found in the literature. From matrix formulations which try to explain the relation between the true pulse height and the measured pulse height, to single event reconstruction (SER) approache which tries to recover the overlapped pulses one by one [3].

SER aims to use a proper mathematical model for pulse reconstruction, then recovering the next overlapped pulses by subtracting the reconstructed pulse from the waveform. By this procedure all pulse information can be obtained, including pulse height, shape, and arrival time. For the case of energy spectroscopy, where only the true pulse heights are desired, a similar but simpler approach has been recently proposed by Lee et al. [4]. In this method the tail of each pulse is extrapolated by a monoexponential model, in order to estimate the pulse amplitude at the peak time of the next pulse. This amplitude is then subtracted from the measured peak amplitude of the next pulse, and the corresponding true pulse height is calculated. In this approach, nonlinear least squares (NLS) fitting is used for pulse tail extrapolation. NLS, as an iterative method with potentially high computational costs, may not be the best choice for processing large amounts of data, as in radiation spectroscopy applications.

The key motivation of the present study is to replace the NLS method by a non-iterative inetgration-based method. The proposed strategy is tested on the experimental data of a NaI(Tl) scintillation detector.

The pile-up correction method

The idea of this study is to recover the true height of each overlapped pulse via extrapolating the tail of its previous pulse. The amplitude of the extrapolated pulse is calculated at the peak time of the pulse under study, then subtracted from its measured peak amplitude (see Figure 1).

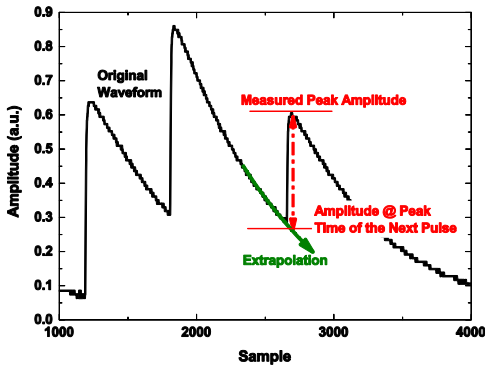

Figure 1. Schematic pile-up correction for an individual pulse inside a waveform

For Pulse tail extrapolation, instead of a NLS approach, a fast non-iterative method is used. Assume a monoexponential model for the pulse tail as follows:

$$V[i] = A \exp(-\theta\, i) \qquad (1)$$

where V[i] represents a discrete form of the pulse data where i=1, 2, 3, …, N, and A and θ are the unknown model parameters. It can be shown that V[i] is the solution of the following integral equation [3]:

$$V[i] = -\theta \int V[i] + A \quad (2)$$

where ∫V[i] shows the discrete first-order integral of V[i]. Having known both V[i] and ∫V[i], a system of linear equations can be solved based on Eq. 2 to obtain A and θ.

Experimental setup

A ^{137}Cs source of nearly 10 µCi activity was placed at two different distances with respect to a NaI(Tl) scintillation detector coupled with a photomultiplier tube. All setup was shielded by lead bricks. Detector data was read out by a preamplifier with a time constant of nearly 30 µs, then digitized by an oscilloscope and saved in a personal computer for further calculations.

Results and discussion

Separately for each of the two experimental datasets mentioned above (let's call them a and b for which the measured count rates were about 14 and 23 kcps, respectively), the recorded signals were first smoothed by a moving average filter of window size 5, then the first derivative of the signals calculated. Both the start time and peak time of the pulses were calculated by setting an appropriate threshold on the derivative signal. In the next step, the proposed pile-up correction method was applied, and the corrected pulse heights were used to calculate the energy spectra. Figures 2a and b show the results for datasets a and b, respectively.

In Figures 2a and b, two additional spectra are also plotted for comparison: the spectrum calculated by an extrapolation strategy but with NLS fitting (the 'NLS' case), and the spectrum calculated simply by the pile-up distorted pulse heights without any correction (the 'uncorrected' case).

Figure 2 shows that the proposed method, despite its simple and non-iterative nature, can perform as a fast alternative to NLS method with quite similar results. A comparison with the uncorrected spectra is also beneficial, in which the pile-up effect severely distorts and/or shifts the spectrum characteristics like photo-peak, Compton edge and back-scatter peak.

Conclusions

A simple, fast, non-iterative method was proposed for a pulse tail extrapolation strategy as part of a pile-up correction algorithm. A comparison with the conventional NLS method showed comparable functionality of the proposed method, which can be used for fast processing of large amounts of nuclear data.

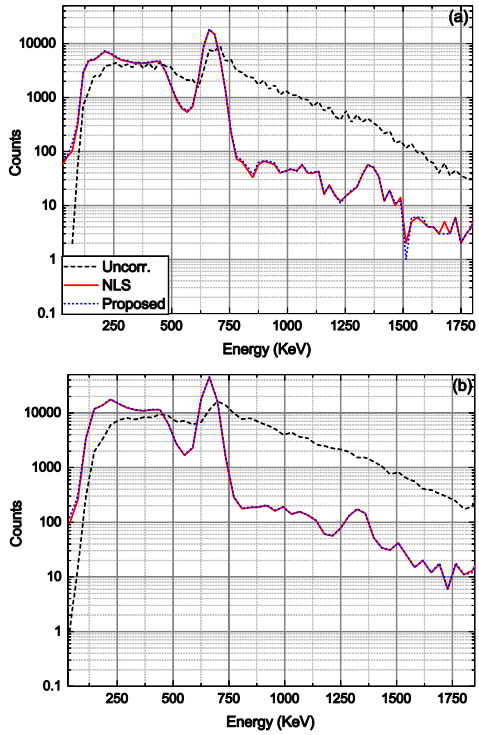

Figure 2. Energy spectra calculated by the proposed method for two datasets of count-rates a) 14 and b) 23 kcps, respectively. Results of using NLS method, as well as the uncorrected spectra are also illustrated

Acknowledgments

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