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Pulse pile-up correction: A comparison between pulse-tail linear extrapolation and trapezoidal pulse shaping

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Abstract

In radiation spectroscopy, there are mechanisms that displace the main spectrum characteristics (e.g. photo-peaks) and degrade their information. A very important mechanism of this type is pulse pile-up, due to which the measured pulse heights are shifted from their actual values. There exist various solutions to this problem, including pulse tail extrapolation and pulse shaping approaches. In the present study, a simplified "linear" extrapolation strategy is introduced and results are compared with those of the well-established "trapezoidal" pulse shaping method. Experimental assessment by using the data of a NaI(Tl) scintillation detector shows a good agreement between both strategies.

Keywords: Energy spectrum, Linear fitting, Pulse pile-up, Trapezoidal shaping.

Introduction

As a particle interacts with a radiation detector, an electric pulse is generated at the detector output, usually read out by a pre-amplifier circuit. The energy spectrum is then obtained by calculating the height-distribution of those pulses. The overlapping of adjacent pulses is called the pulse pile-up phenomenon, which distorts the information of the energy spectrum characteristics [1]. There are different methods to deal with this problem, including the pulse shaping [2] and the pulse information recovery [3] methods. By shaping, the pulses become narrower so that their overlapping is reduced. By information recovery, the true pulse amplitudes are estimated numerically.

Pulse tail extrapolation is a simple and efficient information recovery approach [4], in which the pulse tail data that is not intercepted by the next pulse is used to extrapolate the distorted part. In this way, there will be a new reference line against which the correct height of the next pulse is calculated. Usually, an exponential model is used for fitting the data by a nonlinear least squares (NLS) algorithm, which is an iterative, potentially time-consuming method [5]. In the present study, a linear model (instead of the conventional exponential model) is proposed, which can reduce the numerical complexity of the calculations, while maintaining the quality of the pile-up correction results. In addition, results of trapezoidal pulse shaping [2], as a well-established shaping strategy, are also calculated and compared.

The proposed strategies

The proposed linear extrapolation strategy is based on the idea that a time-dependent function can be approximated by a linear model if approximation is limited to short time-intervals. In the proposed solution, the recorded data (see Figure 1 for instance) were first smoothed by a moving average filter. Then the first derivative of the pulses was calculated. By comparing the derivative signal with a suitable threshold level, the pulse start times and peak times were determined.

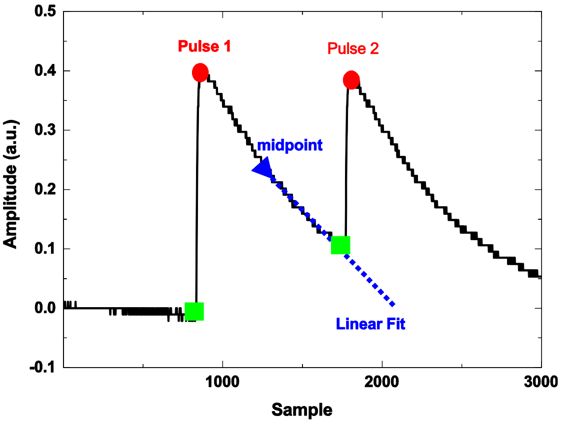

Figure 1. A scheme of the proposed pile-up correction method. Green squares show the pulse start times and red circles show the pulse peak times. The blue triangle symbolically represents a calculated midpoint

Then the midpoints of the peak time of each pulse and the start time of the next pulse were determined. For linear extrapolation, only data between the midpoint and the start point of the next pulse was used to be more consistent with a linear model as follows:

$$V[i] = ai + b, \quad i \in [1, N] \tag{1}$$

where V[i] represents the discrete-form pulse data. Solving a system of linear equations based on Eq. 1 gives the unknown parameters a and b:

$$\begin{bmatrix} 1 & 1 \\ 2 & 1 \\ \vdots & \vdots \\ N & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} V[1] \\ V[2] \\ \vdots \\ V[N] \end{bmatrix} \tag{2}$$

Finally, the corrected height of the next pulse (for instance, Pulse 2 in Figure 1) is calculated by subtracting the new reference line from its measured height.

Trapezoidal shaping, on the other side, gives for the initial pulse V[i] an output S[i] as follows [2]:

$$S[i] = S[i-1] + V[i] - V[i-k] - V[i-l] - V[i-k-l] \qquad (3)$$

so that m = l - k is the length of the upper base of the trapezoid. In this study, l = 10 and k = 5 were selected.

Experimental setup

A set of experimental data was prepared using a NaI(Tl) scintillation detector with a crystal size of 38 × 50.5 mm^2, exposed to a ^{137}Cs source of ~10 µCi activity (recorded count rate of 23 kcps). The detector was connected to a preamplifier (time constant ~30 µs), with outputs digitized and stored in a computer.

Results and discussion

Figure 2 shows the uncorrected ^{137}Cs energy spectrum as well as the spectra calculated by both linear extrapolation and trapezoidal shaping.. Both methods work almost similarly in retrieving the spectrum information. The main spectrum characteristics, i.e. photo-peak, Compton edge and backscatter peak are specified in the figure. Figure 2 also shows the energy spectra calculated by using the exponential (instead of linear) model and the NLS fit [4]. There is a very good agreement between the results of the proposed method and the exponential fitting method, except that the proposed method is a non-iterative, quite simpler algorithm for fast data processing.

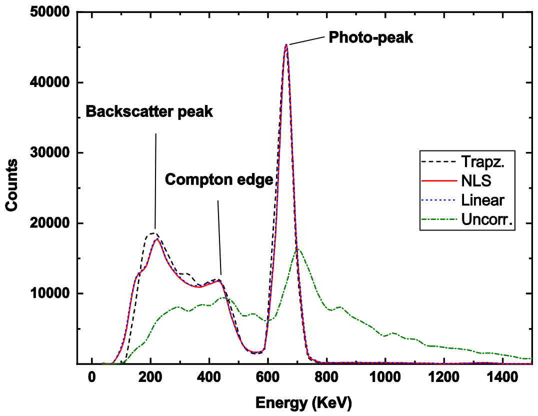

Figure 2. Energy spectra calculated by the proposed linear extrapolation method, exponential extrapolation using NLS algorithm, and trapezoidal shaping. The uncorrected spectrum is also shown for comparison

Table 1 shows the area under photo-peak and full width at half maximum (FWHM) for the spectra of Figure 2. In both NLS and linear methods, data fitting can have unacceptable (negative, complex, etc.) results, especially at severe pile-up cases where datapoints are insufficient. These results are removed from the spectrum, which is the reason for the slightly lower counts under photo-peak for these methods. At severe pile-up cases, the shaping method gives output signals with degraded energy information, which smears the energy resolution.

Table 1. Area under photo-peak (AUP) and FWHM for the spectra of Figure 2

Method	AUP (counts)	FWHM (keV)
Trapz.	3,119,888	65
NLS	3,017,922	61
Linear	3,065,818	61

Conclusions

A pile-up correction strategy based on linear extrapolation of pulse data was proposed, implemented and evaluated. A good agreement was observed between the results of the proposed method and the exponential extrapolation method. Thus, the proposed method, with its simpler formulation and non-iterative nature, can be a better candidate for fast data processing in radiation detection systems. The shaping method is faster than both extrapolation methods, but under high count-rates, it suffers from a degraded energy resolution.

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