Deep Learning-based Trapezoidal Pulse Height Estimation Methods for Pile-up Correction in High Radiation Environments

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1. Introduction

High radiation environments can lead to pile-up, making gamma spectroscopy analysis challenging. For this reason, retrieving the original spectrum through pile-up correction is crucial.

Recently, there has been a study on deep learning-based piled-up pulse height correction using exponential pulse [4] in real-time-based approach in the field. To enhance robustness to unpredictable noise, applying trapezoidal shaping is considered in this study. Additionally, trapezoidal signal exhibits an extended peak duration, allowing accurate height measurement in the case of a single pulse [1-3]. But the extended duration leads to a higher occurrence of pile-up at the peak, causing challenges in peak detection.

In this study, we propose a novel approach for detecting peaks in piled-up trapezoidal signals to improve the recovery rate of the identified peaks. To evaluate the performance of the study, we employed the detection rate as a metric**.** Our work empirically shows that peak detection method can provide high performance in gamma spectroscopy.

2. Material and Methods

2.1 Experiment setup

We conducted the experiment to obtain the exponential pulse.

We utilized a LaBr3 scintillation detector from Saint-Gobain measuring 0.381 cm × x 0.381 cm, and did not include a preamplifier. We used ^{152}Eu, ^{137}Cs, ^{60}Co as point-type sources in this study. The detector output signals were amplified using a CAEN A1423B and digitized by a DT5730 operating at a rate of 500 MSPS. The measured exponential pulses were individually recorded within a 1 μs window, corresponding to a 500-channel signal, as raw data. The peak used in the trapezoidal shaping process was identified based on the raw data provided.

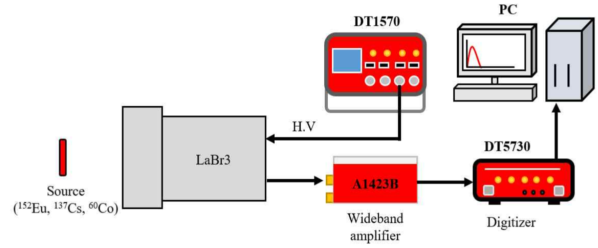

Fig. 1. Experimental setup

2.2 Trapezoidal pulse shaping

When estimating height, it is important to ensure that shaping from an exponential pulse to a trapezoidal pulse maintains consistency in the height information. Shaping into a trapezoidal pulse requires extracting peak values from the exponential pulse. The extracted peak value is utilized to determine the height of the trapezoidal pulse, resulting in equivalent peak as the exponential pulse. After calculating the height of the trapezoidal pulse, adjustments to its shape can be made through iterative modifications of the code settings.

The trapezoidal pulse is expressed by the following equation Eq. (1) where H is the height of the pulse, R and F is rise time, fall time of the pulse, and D is the total length of the pulse.

In this study, we defined the rise and fall time, width of the height flat top and length of a trapezoidal pulse are each defined by 16 bins, 32 bins, and 64 bins (as we define 2 ns as 1 bin).

$$T.P. = \begin{cases} \frac{H}{R} \times t, \; t < t_R \\ H, \; t_R < t < t_L - t_F \\ H - \frac{H}{F} \times (t - (L - F)), \; Otherwise \end{cases} \quad (1)$$

2.3 Peak Detection Method

Identifying the accurate peak location in a trapezoidal signal is crucial for detecting the specified peak of each piled-up pulses. To accurately determine the location, we observed a consistent pattern where slopes occurred adjacent to the peaks. Based on this observation, we conducted differentiation on the piled-up signal to detect these slopes. However, conducting differentiation conventionally may result in overlapping rising and falling slopes, complicating slope distinction. To address this, we separated the positive and negative differentials, thus detecting the location of each differentiation's slope. Subsequently, we designated the end of each differentiated slope as the peak finding location. The right end of the pre-differentiated signal's slope is detected as shown in Fig. 2. It allows slicing to the left based on this location to obtain slope pulses containing height information.

Based on this observation, we determined the detection rate using the sliced pulse given by Equation. (2).

$$\text{Detection rate} = \left(\frac{Height\ pulse\ count}{Actual\ pulse\ count} \times 100\right) (\%) \quad (2)$$

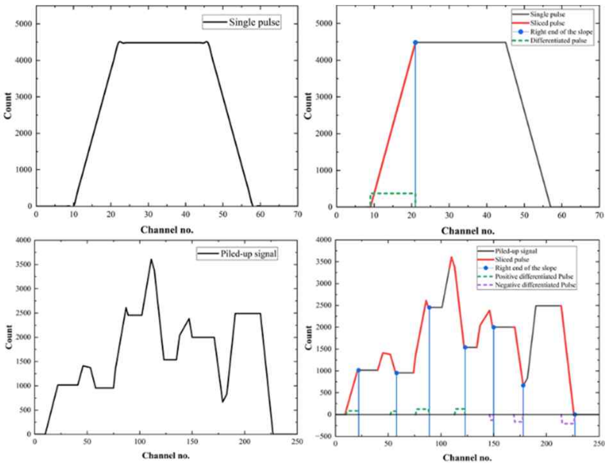

Fig. 2. Peak detection using differentiation method

3. Result and Discussion

3.1 Detection rate of piled-up signal

We generated a series of piled-up signals by overlaying 1 to 10 pulses within a window length of 496 bins. These pulses were generated following a Poisson distribution (λ=3). This process allowed us to assess our peak detection method based on the detection rate associated with the pile-up interval of trapezoidal pulses.

Table. 1. Detection rate based on the interval of the pulse

Interval between pulses					
12 bins	**14 bins**	**16 bins**	**18 bins**	**20 bins**	**22 bins**
34.4%	39.5%	36.7%	95.3%	99.6%	99.7%

As shown in Table. 1, intervals ranging from 12 bins to 16 bins exhibit detection rates below 40%. From the interval of 18 bins onward, the method successfully detects the sliced pulses with a detection rate ranging from over 95% to 99.7%. We found that the detection rate is low within an interval of up to 16 bins. This is due to the shorter duration of the interval in comparison to the slope, resulting in the inability to detect peaks. However, beyond 18 bins, it exhibited reasonably good performance in peak detection. This suggests the proposed pulse detection algorithm operates effectively only when the rise or fall time of the trapezoidal pulse exceeds a certain interval. However, beyond this interval, its potential efficacy in high radiation environments becomes apparent.

Table. 2. Comparison of detection rates between exponential pulse and trapezoidal Pulse

Interval between pulses	Exponential pulse detection rate	Trapezoidal pulse detection rate
12 bins	52.2%	34.4%
16 bins	82.8%	36.7%
24 bins	93.8%	99.8%
32 bins	96.6%	99.7%
40 bins	99.3%	100.0%

Table. 2 presents the comparison of detection rates between exponential pulse [4] and trapezoidal pulse. For intervals extending up to 16 bins, reduced accuracy in detection rates was showed. However, from 24 bins the detection rate significantly improved, demonstrating superior performance of the trapezoidal pulse compared with the exponential pulse.

3.2 Pile-up correction using CNN model

Implementing the CNN-based pulse height estimation model from [4], we used sliced pulses obtained through the peak detection method as input. We observed that the gamma-ray spectrum results approximately matched those of the reference spectrum when correcting for pile-up signals as shown in Fig. 3.

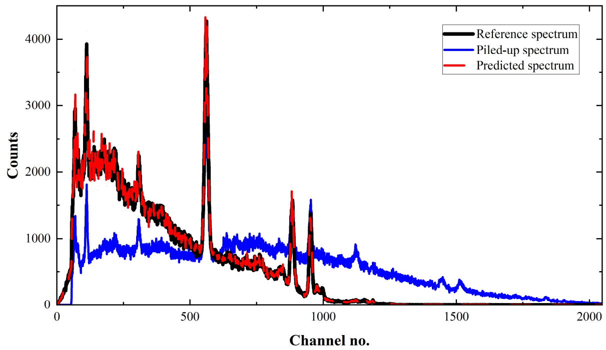

Fig. 3. Reference spectrum, piled-up spectrum, and predicted spectrum of pile-up correction results in CNN model.

4. Conclusion

In this study, we devised a method to detect the peak in the trapezoidal piled-up signal. Our results showed the peak detection performance of piled-up trapezoidal signals. However, we observed upon 16 bins, piled-up scenarios posed challenges for peak detection due to the short interval. In future research, we aim to enhance our peak detection methodology by incorporating the second derivative method to detect peaks within shorter intervals.

ACKNOWLEDGEMENT

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