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A comparison of different discrimination parameters for the DFT-based PSD method in fast scintillators

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HIGHLIGHTS

- The spectrum difference between neutron pulse and γ-ray pulse was investigated.
- The DFT-based PSD with different parameter definitions was assessed.
- The way of using the ratio of magnitude spectrum provides the best performance.
- The performance differences were explained from noise suppression features.

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ABSTRACT

Although the discrete Fourier transform (DFT) based pulse shape discrimination (PSD) method, realized by transforming the digitized scintillation pulses into frequency coefficients by using DFT, has been proven to effectively discriminate neutrons and γ rays, its discrimination performance depends strongly on the selection of the discrimination parameter obtained by the combination of these frequency coefficients. In order to thoroughly understand and apply the DFT-based PSD in organic scintillation detectors, a comparison of three different discrimination parameters, i.e. the amplitude of zero-frequency component, the amplitude difference between the amplitude of zero-frequency component and the amplitude of base-frequency component, and the ratio of the amplitude of base-frequency component to the amplitude of zero-frequency component, is described in this paper. An experimental setup consisting of an Americium–Beryllium (Am–Be) source, a BC501A liquid scintillator detector, and a 5Gsample/s 8-bit oscilloscope was built to assess the performance of the DFT-based PSD with each of these discrimination parameters in terms of the figure-of-merit (based on the separation of the event distributions). The third technique, which uses the ratio of the amplitude of base-frequency component to the amplitude of zero-frequency component as the discrimination parameter, is observed to provide the best discrimination performance in this research.

1. Introduction

Organic scintillation detectors have often been used for the detection and spectroscopy of a wide assortment of radiations. When they are used as neutron detectors, pulse shape discrimination (PSD) is an essential requirement because all neutron fields coexist with an associated γ-ray component, arising as a result of scattering reactions of the neutrons with materials in the environment and as direct by-products of the primary reaction producing the neutron field (Knoll, 2000). Besides, by applying the n/γ PSD technique, it is possible to measure the spectra of neutrons and γ rays concurrently in a single measurement.

More recently, a number of techniques for PSD have been implemented in the digital domain as digital electronic platforms have become available with the requisite speed and cost. According to the characteristics of the separation parameters, these discrimination methods can be classified as a time domain PSD and frequency domain PSD (Saleh et al., 2012). The time domain PSD, such as the zero crossing method (Nakhostin and Walker, 2010), the charge comparison method (Ambers et al., 2011), the correlation method (Kornilov et al., 2003), the curve-fitting method (Marrone et al., 2002) and the method of pulse gradient analysis (PGA) (D′ Mellow et al., 2007), can usually provide real-time, digital characterization of environments where neutrons and γ rays coexist. But because the time domain features are naturally highly

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dependent on the signal amplitude at specific times, these methods based on time domain features are sensitive to the natural variance and noise in the pulse response arising from the photomultiplier tube (PMT) and the measurement circuit, and therefore the discrimination performance has a great dependency on the de-noising algorithm. The frequency domain PSD, obtained by transforming the digitized scintillation pulses into frequency coefficients by using any frequency transform, such as Discrete Fourier Transform (DFT) or Discrete Wavelet Transform (DWT), is more robust to the variance and noise in the detection system and therefore does a better discrimination than the time domain PSD (Liu et al., 2010; Arafa et al., 6–7 APRIL, 2009; Yousefi et al., 2009; Shippen et al., 2010). For the DWT-based PSD is usually highly computationally intensive and hence not suitable for real-time field measurements, more and more attention has been given to the DFT-based PSD.

In order to combine the advantage of insensitivity to pulse variation and noise associated with spectral analysis with that of real-time implementation, generally only the first two components of DFT, i.e. the zero-frequency component and the base-frequency component, have been calculated. It is obvious that the method of defining the discrimination parameter from these two components has a great effect on the performance of the DFT-based PSD. In this work, we described the comparison of figure-of-merits (based on the separation of the event distributions) determined with three different discrimination parameters for the DFT-based PSD method on events from a fast scintillation detector.

This paper is organized as follows: first, the principle of DFT-based PSD and three definitions of discrimination parameters are described in Section 2. Second, a detailed description of the experimental environment is given in Section 3. The results and discussion are given in Section 4. Finally, Section 5 concludes this paper.

2. The principle of DFT-based PSD with different discrimination parameters

2.1. The principle of DFT-based PSD

Assuming that the digitalized scintillation pulse signal is $x(n)(n = 0,1,...N-1)$, its discrete Fourier transform (DFT) $X(k)$ can be obtained through the following analysis equation (Oppenheim et al., 1999)

$$X(k) = \sum_{n=0}^{N-1} x(n)\exp\left(-j\frac{2\pi}{N}nk\right) \quad k = 0,1,...,N-1 \tag{1}$$

where the integer variable n is the discrete time index, N is the sample length, and the integer index k represents the discrete frequency variable, which corresponds to an actual frequency of $2k\pi/N$ rad/s or kF_s/N Hz where F_s is the sampling frequency in units of Hz. According to Eq. (1), we also can obtain the magnitude spectrum $|X(k)|$ and the power spectrum $|X(k)|^2/N$ of the digitalized scintillation pulse signal, respectively.

A typical pulse shape according to the six parameter function of Marrone's model (Marrone et al., 2002; Liu et al., 2010) for each radiation type is given in Fig. 1. It is clearly shown that the neutron-induced pulse decays more slowly than the pulse stimulated by γ ray, because neutrons show great energy loss rate during their interaction than γ rays.

The corresponding magnitude spectrum of each radiation type is calculated by using Eq. (1). The results show that there is little difference between the magnitude spectrum of neutron-induced pulse and that of γ-ray pulse at higher frequency, and hence only some lower frequency components of DFT are given in Fig. 2. It can be clearly seen from Fig. 2 that at $k = 0$, i.e. at zero-frequency, there is a distinct difference between the magnitude spectrum of neutron pulse and that of γ-ray pulse, which can be used as a prominent feature to discriminate neutrons and γ rays.

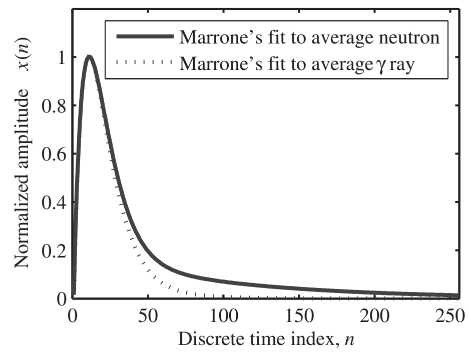

Fig. 1. A plot of normalized amplitude versus discrete time index for an average neutron (solid line) and γ-ray pulse shape (dot line).

2.2. Three definitions of discrimination parameters of DFT-based PSD

Exploiting this feature and considering the requirement of real implementation, three typical definitions of discrimination parameters have been proposed as follows.

(1) The first method of defining the discrimination parameter, which directly uses the feature that $|X(0)|$ of neutron pulse is much bigger than that of γ-ray pulse, is described as

$$d_{11} = \frac{1}{N}|X(0)| \text{ or } d_{12} = \frac{1}{N}|X(0)|^2 \tag{2}$$

(2) The second method of defining the discrimination parameter, which is proposed by G. Liu et al. (Liu et al., 2010), is described as

$$d_{21} = \frac{1}{N}(|X(0)| - |X(1)|) \text{ or } d_{22} = \frac{1}{N}\left(|X(0)|^2 - |X(1)|^2\right) \tag{3}$$

(3) The third method of defining the discrimination parameter, which is proposed by Arafa et al., 6–7 APRIL (2009), is described as

$$d_{31} = 1 - \frac{|X(1)|}{|X(0)|} \text{ or } d_{32} = 1 - \frac{|X(1)|^2}{|X(0)|^2} \tag{4}$$

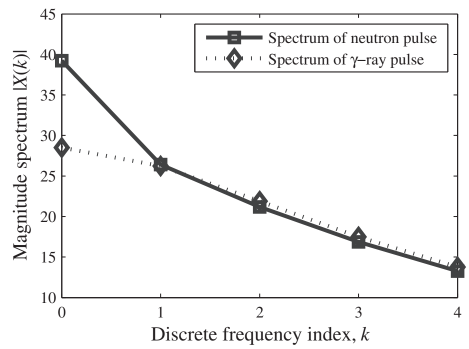

Fig. 2. The lower frequency components of the magnitude spectrum of the average neutron pulse (solid line) and that of the average γ-ray pulse (dot line).