Nuclear Instruments and Methods in Physics Research A 858 (2017) 22–29

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Peak center and area estimation in gamma-ray energy spectra using a Mexican-hat wavelet

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ARTICLE INFO

Keywords:
Gamma-ray spectra
Wavelet analysis
Peak area calculation
Peak center calculation

ABSTRACT

Wavelet analysis is commonly used to detect and localize peaks within a signal , such as in Gamma-ray energy spectra. This paper presents a peak area estimation method based on a new wavelet analysis. Another Mexican Hat Wavelet Signal (MHWS) named after the new MHWS is obtained with the convolution of a Gaussian signal and a MHWS. During the transform, the overlapping background on the Gaussian signal caused by Compton scattering can be subtracted because the impulse response function MHWS is a second-order smooth function, and the amplitude of the maximum within the new MHWS is the net height corresponding to the Gaussian signal height, which can be used to estimate the Gaussian peak area. Moreover, the zero-crossing points within the new MHWS contain the information of the Gaussian variance whose valve should be obtained when the Gaussian peak area is estimated. Further, the new MHWS center is also the Gaussian peak center. With that distinguishing feature, the channel address of a characteristic peak center can be accurately obtained which is very useful in the stabilization of airborne Gamma energy spectra. In particular, a method for determining the correction coefficient k is given, where the peak area is calculated inaccurately because the value of the scale factor in wavelet transform is too small. The simulation and practical applications show the feasibility of the proposed peak center and area estimation method.

1. Introduction

The presence of gamma-ray emitters in a sample is determined by identifying their characteristic peaks in the gamma-ray energy spectrum. A characteristic peak always overlaps the continuous background and can even overlap the regions of interest of the neighboring peaks. Thus, it is very difficult to automatically find the characteristic peak center and accurately calculate the peak area. There are some well-known methods for localizing peaks and estimating peak areas, such as Sterlinski's method, Kemper's method, Kosina's method, among others [1]. To calculate a net peak area, the correlation coefficient method can be used to subtract the background or overlapping peaks [2]. To determine whether a characteristic peak exists, some methods are given for calculating the decision thresholds for the radionuclides identified in gamma-ray spectra [3–5]. Benchmarks of the non-parametric Bayesian deconvolution method have implemented in the SINBAD code for X or gamma rays spectra processing [6].

A wavelet analysis method for searching for peaks in Gamma-ray energy has been presented recently [7–9]. In fact, Gaussian peak area can be estimated as well based on the wavelet analysis. It is assumed that a characteristic peak in the gamma-ray energy spectrum is a Gaussian signal that overlaps a linear background. (Though the background is nonlinear sometimes, it can be curve fitted as a smooth line. Similarly, perhaps the peak is a Poisson signal sometimes, but it is also curve fitted as a smooth Gaussian.) After the wavelet analysis, a Gaussian signal is transformed into a MHWS, and the background is subtracted. Based on the MHWS, the characteristic peak center and the peak area can be calculated easily. Moreover, if the characteristic peak overlaps the regions of interest for the neighboring peaks, thereby decreasing the value of the scale factor in the wavelet transform, then the resulting precision of the characteristic peak center and the peak area will not be influenced. Thus, the method achieves airborne gamma-ray energy spectra stabilization.

2. Wavelet analysis of a Gaussian signal

There are two important concepts as shown in Eqs. (3) and (5), which are proved in the paper.

A Gaussian signal is given by the following expression:

$$x(t) = H\exp(-\frac{t^2}{2\sigma^2}) \tag{1}$$

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http://dx.doi.org/10.1016/j.nima.2017.03.029
Received 6 December 2016; Received in revised form 15 March 2017; Accepted 15 March 2017
Available online 23 March 2017
0168-9002/

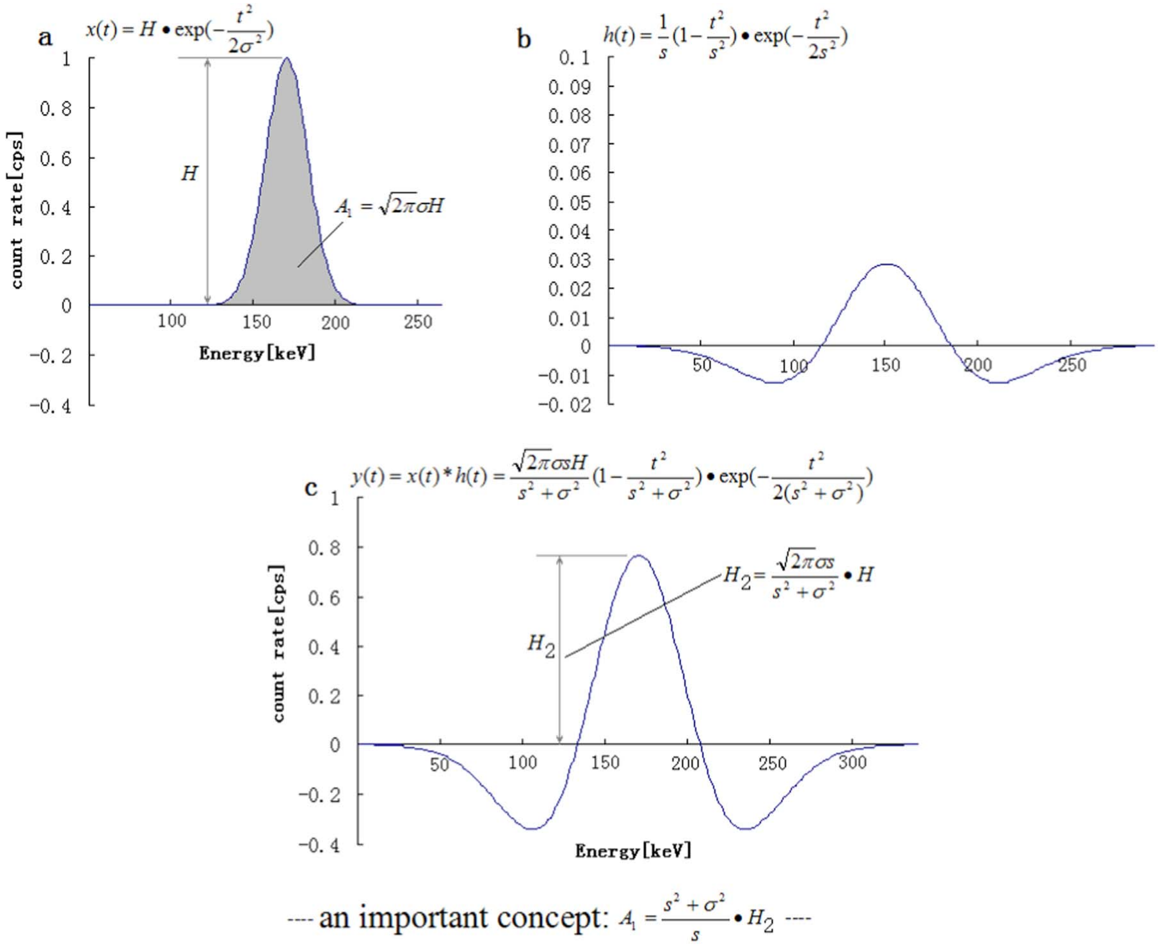

Fig. 1. Convolution of a Gaussian input signal (a) with the impulse response (b) and the output response of the system (c).

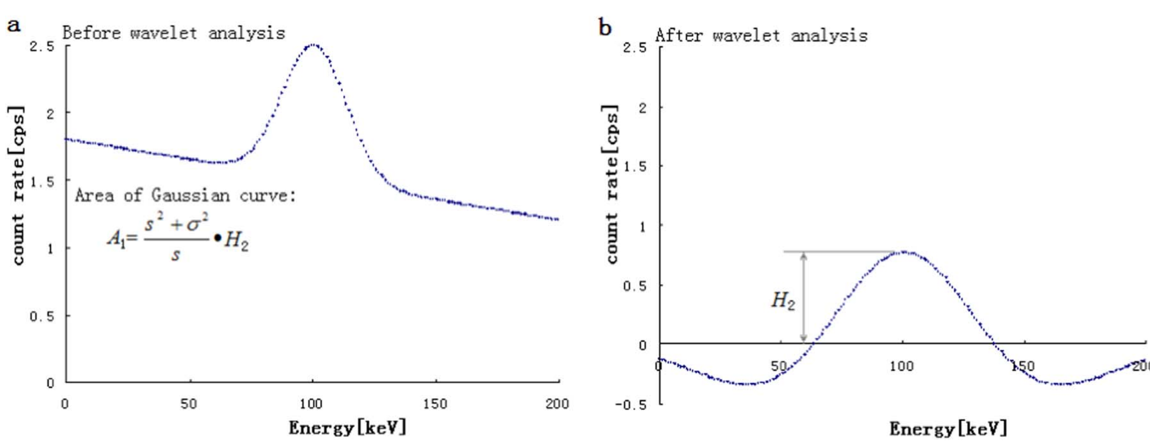

Fig. 2. Gaussian signal overlapping a baseline (a) and the new signal (b) without baseline after performing wavelet analysis.

where H is the amplitude and σ is the variance.

The impulse response $h(t)$ is given by

$$h(t) = \frac{1}{s}(1 - \frac{t^2}{s^2})\exp(-\frac{t^2}{2s^2}) \tag{2}$$

where s is the scale factor in the wavelet transform.

The transformation of an input signal x(t) into an output signal y(t) by a linear time-invariant system is mathematically expressed as the convolution of the input signal and the impulse response of the system. The convolution is commonly written using the star (*) symbol. y(t) is given by the following expression:

$$y(t) = x(t)*h(t) = \frac{\sqrt{2\pi}\sigma sH}{s^2 + \sigma^2}(1 - \frac{t^2}{s^2 + \sigma^2})\bullet \exp(-\frac{t^2}{2(s^2 + \sigma^2)}) \tag{3}$$

where H is the amplitude, σ is the variance, as shown in Eq. (1), and s is the scale factor in Eq. (2).

According to Eq. (3), the amplitude of $y(t)$ can be inferred:

$$H_2 = \frac{\sqrt{2\pi}\sigma sH}{s^2 + \sigma^2} \tag{4}$$

As shown in Fig. 1(a), the Gaussian peak area can be calculated using Eq. (5):