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Heuristic approach for peak regions estimation in gamma-ray spectra measured by a NaI detector*

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Abstract In this paper, a heuristic approach based on Slavic's peak searching method has been employed to estimate the width of peak regions for background removing. Synthetic and experimental data are used to test this method. With the estimated peak regions using the proposed method in the whole spectrum, we find it is simple and effective enough to be used together with the Statistics-sensitive Nonlinear Iterative Peak-Clipping method.

Key words peak regions, gamma-ray spectra, background elimination

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1 Introduction

In general, the background of a gamma ray spectrum can be approximated by a linear function within short intervals in the vicinity of a peak or multiple peaks under consideration. Up to now several algorithms have been proposed to resolve this problem[1—11]. Among these methods, the SNIP (Statistics-sensitive Nonlinear Iterative Peak-Clipping) Algorithm is considered as the most efficient approach[1—6]. It is a multi-pass peak clipping loop that replaces each channel value $N(x)$ with the lesser one between $N(x)$ and the mean $\overline{N}[x,w(x)]$. Herein, $\overline{N}[x,w(x)] = [N(x+w)+N(x-w)]/2$ and the scanning width w is fixed to two times of the peak's FWHM(full width at half maximum) in channel x. Afterwards, Morhac[2—4] proved that background elimination using the SNIP method is determined by the loop times as shown in Fig. 1, i.e., the background can be removed completely ($\sim 100\%$) in the region of peaks while the loop times m approximately equals $w/2$. Herein, w is the real width of an object (peak, doublet peaks, multiplet peaks) that should be preserved. Too big loop times account for the remaining background residual under peaks[2].

That is, if we know the width of an object, we can select a suitable value for the loop times, and then the background under this object can be removed completely by the SNIP method. The more accurately the real width of the object is determined, the more precise and rapid the background eliminating will be. However, the width of an object is hard to be calculated precisely and little work has been done about this until now. Rough values used in the background elimination by the SNIP method always give uncompleted elimination and cannot fit different spectra.

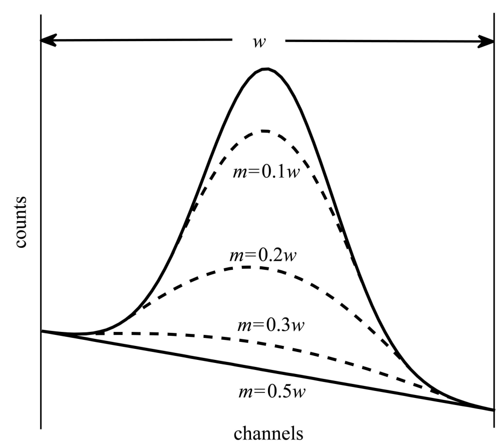

Fig. 1. Background elimination with different m using the SNIP method. Here, w is the real width of the object.

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In this paper, we will consider this problem and develop a simple program based on an extension of Slavic's peak searching method[10, 11] to estimate the width of peak regions in smoothed gamma-ray spectra. As described by Morhac[2—4], if we know the widths of the peak regions, the background in these regions can be easily calculated with the SNIP method. The description of this method and its application is divided into four sections. In section 2, the extending method based on Slavic's peak searching method is presented briefly. In section 3, synthetic and experimental spectra are used to test this method. Conclusions will be given in the last section.

2 Description of the method

Because of the influence caused by a declining linear background and hidden peaks, the peaks in the whole spectrum are unsymmetrical. The width of the left part of the peak is less than its real value, especially in the first peak of the spectrum. In addition, because of the slowly declining background, this influence becomes smaller as the number of channels increases. In this section, we will present a heuristic approach to correct this influence and get the real width of the peak or multiplet in the spectrum. The proposed method is divided into four steps. The first step is searching peaks to get the initial regions. The second step is to merge adjacent overlapping regions. The third step is using a heuristic approach to get the real width of each region in two directions. The last step is to check whether two adjacent corrected regions have the same background.

Following the idea of Slavic[12, 13], peaks can be simply localized by point comparison. Because the content of successive channels $C_{N_{i-1}}$ and C_{N_i} has the relation that:

$$C_{N_i} > C_{N_{i-1}} \ , \tag{1}$$

only in the region of smooth spectra where a peak begins to rise from the bottom up to the top of the peak as shown in Fig. 2, can the peak be characterized by the channels, N_1, N_2, i.e., the first channel and the peak position channel satisfying condition (1), and the value

$$IG = N_2 - N_1 \ , \tag{2}$$

corresponding approximately to the peak's full width at half maximum (FWHM). The initial region of each peak in the spectrum can be estimated approximately by

$$\begin{cases} S = N_2 - IG - 1, \\ K = K_1 = N_2 + IG + 1, \end{cases} \tag{3}$$

i.e., the starting (S) and the final (K) channels with the slope value

$$slope_1 = \frac{C_K - C_S}{K - S} \ , \tag{4}$$

as indicated in Fig. 2.

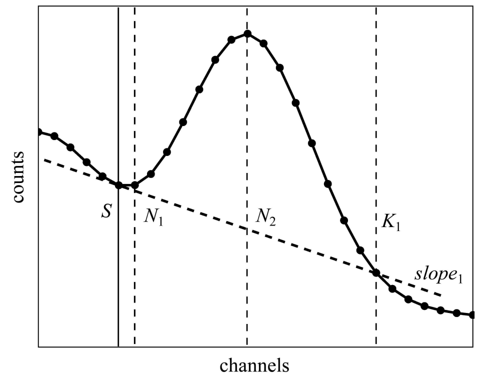

Fig. 2. Locating a peak using the idea of Slavic.

While the initial regions are determined, attention must be paid to the fact that in the case of multiple peaks (as shown in Fig. 3), values with $K_i > S_{i+1}$ will occur. Here, K_i represents the end channel of the ith initial region and S_{i+1} represents the starting channel of the $(i+1)$th initial region. In Fig. 3, there are two regions estimated by the method described above, which we call R_1 and R_2, respectively. The end channel (K_1) of the region R_1 is larger than the starting channel (S_2) of the second region R_2. In this case, we merge the two regions. The merged region is named R_1' with its starting channel S_1 and new end channel K_2.

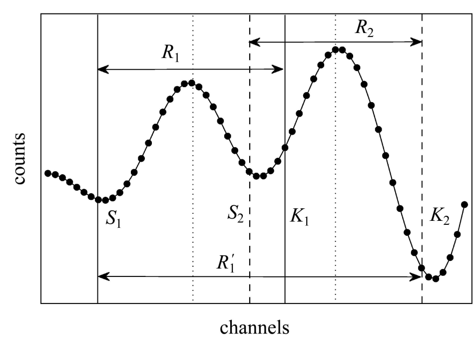

Fig. 3. Merging two overlapping regions.

The heuristic approach is applied in two directions to get the real width of the region. The first direction is from the low energy channel to the higher energy channel to get the real width of the right part of the peak. The second direction is inverse, from higher energy channel to the low energy channel, to get the real width of the left part of the peak.

In the first direction we select the points channel by channel where the value of the channel selected is larger than that of the end point channel of the current region and less than that of the start point channel of the next region. Then the slope values $slope_i$ are calculated as below at the selected point and the starting point of the current region

$$slope_i = \frac{C_i - C_{S_j}}{i - S_j} \ , \tag{5}$$

where $K_j < i < S_{j+1}$. The channel in which the value of the $slope_i$ becomes minimal can be approximately considered as the real end channel of the current region, as shown in Fig. 4.

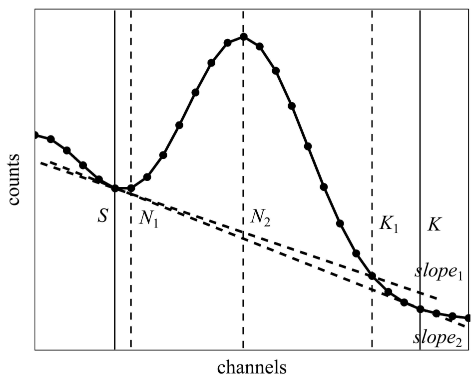

Fig. 4. The first correction of the heuristic approach to get the real end point of a current region.

In the second direction, going from the higher energy channels to lower energy channels, we select the points channel by channel until the value of the selected channel is less than the starting point of the current region and larger than the end point of the previous region. Then, the slope values are calculated as below at the selected point and the end point of the current region

$$slope_i = \frac{C_i - C_{K_j}}{i - K_j} \ , \tag{6}$$

where $K_{j-1} < i < S_1$. The channel in which the value of the $slope_i$ becomes a maximum can be approximately considered as the real starting channel of the current region. Up to this point, the real width of each region has been estimated.

Finally we have check whether the adjacent regions have the same background. If the slopes of adjacent regions are the same, we merge these regions as one region. Assuming that there are n regions in the whole spectra (estimated as above), we use Eq. (5), starting from the first starting point, i.e. $j = 1$, to calculate the slope, where $i = K_j$, K_{j+1}. These values are then compared to check whether they are equal. If so, these two regions are merged into one region. The same procedure is repeated until the last end point is reached.

3 Test and discussion

On the basis of the method described above a program has been written. The program consists of 5 parts. The first part is the smoothing of the measured data using least squares fitting with B-spline basis functions[14] or other smoothing methods[15—19] to improve the quality of the calculation. However, it is not included in this paper. The second part is the determination of the initial regions following the idea of Slavic. The initial regions can be characterized by the start channels (S) and the final channels (K). The third part is to merge the adjacent regions automatically where overlapping occurs. The fourth part uses the heuristic approach to estimate the real width of each region with corrections applied in two directions. The fifth part merges regions that have the same background.

Both synthetic and experimental spectra are investigated in this section. Gamma ray spectra have the characteristic that peaks are wider in the high energy region than those in the lower energy region of the spectrum. We synthesize the spectrum with three Gaussian functions g_1, g_2, g_3 with the pre-known parameters $\sigma_1 = 4$, $\sigma_2 = 5$, $\sigma_3 = 6$ and piecewise linear background under the peak or peak multiplet. The synthetic data are composed with two regions named R_1 and R_2 separated by the line L_1, as shown in Fig. 5(a).

According to Slavic's peak searching method, the start and end channel in each region can be estimated approximately as shown in Fig. 5(b). It can be seen from this sub-figure that the end channel K_1 of the first region is larger than the starting channel S_2 of the second region. In general, as described above, we merge these two regions. The merged region is named R_1' with its start channel S_1 and new end channel K_2 as shown in Fig. 5(c).

In the first correction of the heuristic approach, slope values are calculated and compared to find the real end point in each region. In Fig. 5(d), the new end channel K_2 is found because the value of $slope_2$ is less than the value of $slope_1$.

In the second correction of the heuristic approach, the new starting point in each region is found comparing the slope values. The result is shown in Fig. 5(e). In this sub-figure, the width of each region is approximated to its designed value. The result also proves the correction of the proposed method.

In the last step, we check whether the adjacent regions have the same background. The value of $slope_1$

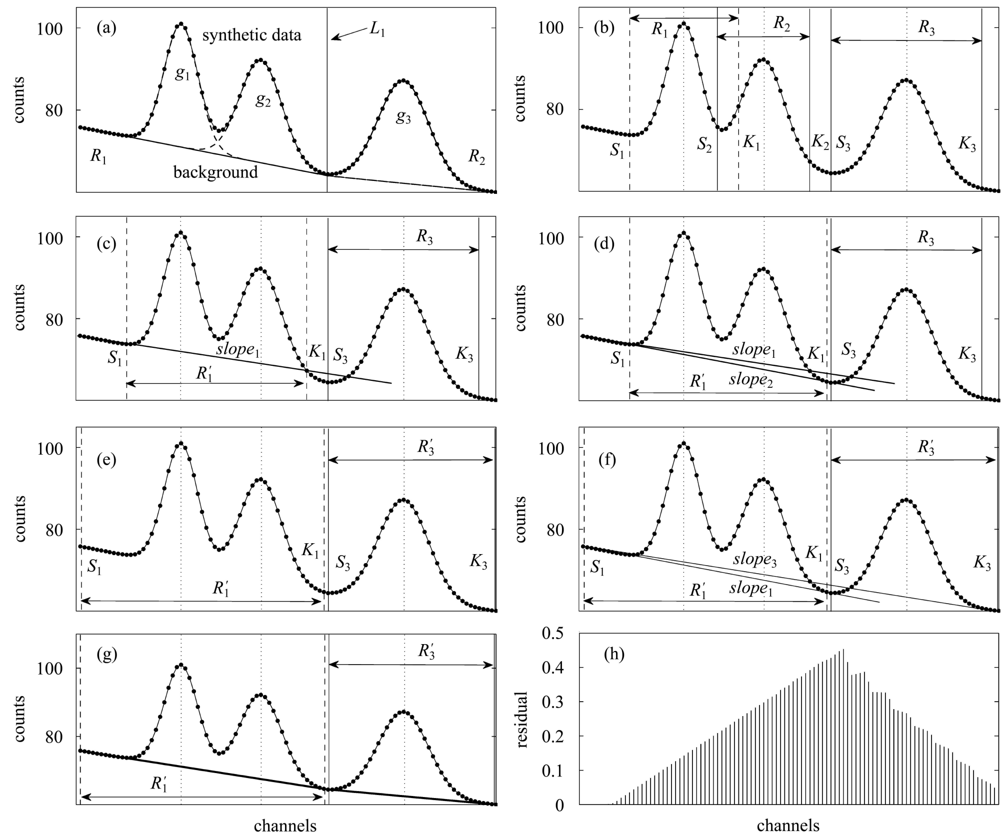

Fig. 5. Estimation of peak regions in the case of synthetic data. (a) Synthetic data with three Gaussian functions. (b) Determination of the initial region with Slavic's peak searching method. (c) Merging two initial regions where overlap occurs. (d) The first correction of the heuristic approach to obtain the real end point in each region. (e) The second correction of the heuristic approach to obtain the real starting point in each region. (f) Comparing the slope values to check whether adjacent regions have the same background. (g) Background estimation using the SNIP method in each calculated region. (h) The residual of the estimated background with the designed background.

in the first region is compared with the value of $slope_3$ in the second region as shown in Fig. 5(f). Because the value of $slope_3$ is larger than the value of $slope_1$, these two regions don't have the same background according to the method described in section 1.

To test the efficiency of the proposed method, the background is estimated with the SNIP method in each investigated region, as shown in Fig. 5(g). It can be seen from this sub-figure that the background is approximately linear under the peak or multi-peaks in each region. Comparing this sub-figure with Fig. 5(a), we find that the estimated background approximates to the original linear background we designed. The residual of the estimated background with the original designed linear background is shown in Fig. 5(h). It can be seen that the residual value is small enough to be omitted compared with the content of the synthetic data.

The smoothed experimental gamma ray spectrum from a mixed radiation source with 512 channels has been measured by a NaI detector over a period of more than 2 h. According to the method described in this paper, the regions are determined by our program as shown in the Fig. 6(a). In this sub-figure, the dashed lines represent the starting points of each region whereas the dashed dot lines represent the end point of each region. Because we know the width of each region, we can estimate the background by the SNIP method in each region. The background of the spectrum estimated by the SNIP method is shown in Fig. 6(b). It can be seen from this sub-figure that under the peaks the background is estimated approximately linearly in each region. Comparing with this removing background method, the background of the same spectrum is also estimated by the SNIP method without pre-calculating the width of each region. We estimate the average FWHM of the whole spectrum by visual inspection, and then calculate the background for the whole region by the SNIP method with the estimated value of the FWHM. The result is

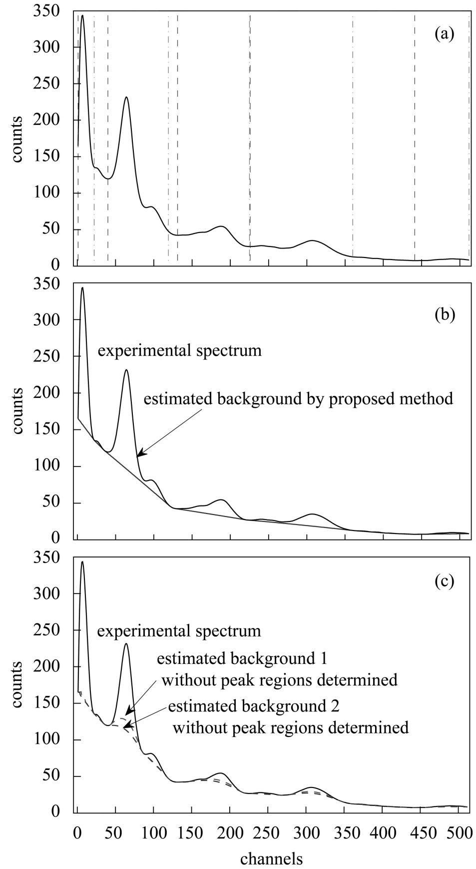

Fig. 6. Estimation of the peak regions in the experimental spectra detected by the NaI detector. (a) Estimation of the peak regions in the experimental spectra with the proposed method. Dashed line: Start point of the current region; dashed dot line: End point of the current region; (b) Background estimation using the SNIP method in each calculated region. (c) Background estimation using SNIP without the peak regions determined.

shown in Fig. 6(c). In this sub-figure, there are two background lines estimated without the peak region being pre-calculated. The first background line, shown by background1, cannot fit the width of each peak, so it cannot estimate the background well which is considered to be a linear background under the object (peak, doublet peaks, multiplet peaks) in the spectrum. Though the second average width of the whole spectrum can fit the first peak well, it can not fit the width of the residual peaks, which is shown clearly in this sub-figure.

4 Conclusion

The main purpose of this paper is not to give a new method to estimate the background of gamma-ray spectra, but rather to emphasize the method to estimate the widths of peak regions. These widths can help us to estimate the background completely while using the SNIP method. The proposed method is based on Slavic's peak searching method to find all peaks in the spectrum, then merge the overlapping regions in the case of multiple peaks. Because of the linear background under the peak, the real width of each peak is different from that without background. To resolve this problem, heuristic approaches with two directions are used to correct the width of regions determined by Slavic's method. In addition, synthetic data have been used to test the corrections of the method. The result shows that the proposed method allows one to obtain the correct regions. Experimental gamma ray spectra have also been used to test its effect on background eliminating if peak regions are determined. With the estimated peak regions obtained by the proposed method in the whole spectra, we conclude that it is effective enough to be used together with the SNIP method.

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