Design of fast digital spectrum stabilization method for UAV radiometry system

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Abstract. The drone radiation measurement system has a sharp increase in demand for environmental radiation monitoring due to its easy manoeuvrability, low aerial survey cost, high patrol efficiency and no personnel safety concerns. In order to adapt to the fast, flexible and efficient characteristics of the drone, the detector for the Unmanned Aerial Vehicle (UAV) radiation measurement generally consists of a plurality of small-sized detectors to form a detection array. Due to the low single crystal count rate and the influence of electronic system temperature and packaging, many detectors of the UAV radiation measurement system will have "spectral drifts", which affects the quality of the synthesized spectrum and affects the accuracy of the whole system. Aiming at the characteristics of UAV spectrum measurement system, a three feature point recognition model is established, and the K-40 feature peak (1.46MeV) is approximated by reverse piecewise summation. Thus, the backscattering peaks and characteristic peaks K-40 of the measured spectrum can be obtained to achieve fast spectrum stabilization. Finally, through Gaussian Mixture Model (GMM) peak estimation and experimental validation, the method can obtain the characteristic peak position accurately, and the time between instrument start-up and automatic spectrum stabilization is less than 2 minutes.

1. Introduction

UAV is an unmanned aerial vehicle operated by radio remote control equipment or its own program-controlled device. Because of its wide use, low cost, no casualty risk and good mobility, quite a few countries, such as the United Kingdom, Canada, the United States and so on, have developed UAV geophysical detection equipment. And it plays an important role in modern society. After the Fukushima nuclear accident in Japan, RMAX-G1 was also used to carry out aerial surveys to detect radiation levels around the nuclear power plant [1-3]. In China, with the development of UAV technology and the needs of environmental radiation measurement, quite a few domestic units have developed UAV radiometric measurement system for environmental monitoring, such as Nuclear Industry Remote Sensing Center, Nanjing University of Aeronautics and Astronautics, Chengdu University of Technology and so on.

In order to adapt to the fast, flexible and efficient characteristics of the drone, the detector for the UAV radiation measurement generally consists of a plurality of small-sized detectors to form a detection array [4]. Due to the low single crystal count rate and the influence of electronic system...
temperature and packaging, many detectors of the UAV radiation measurement system will have "spectral drifts", which affects the quality of the synthesized spectrum and affects the accuracy of the whole system [5-6]. Therefore, the problem of spectrum stabilization must be solved.

Recently, the main methods of spectrum stabilization are hardware spectrum stabilization, reference source spectrum stabilization, characteristic peak spectrum stabilization, etc. They have their own pros and cons [7-11], which are not discussed here. This paper develops a fast dual reference peak spectrum stabilization method based on the characteristic peak of spectra-stabilization and verified in the field environment.

2. Material and methods
In this paper, the dual reference peaks spectrum stabilization method of backscatter peak and K-40 characteristic peak (\(\text{LaBr}_3\)) are studied. Taking the UAV detection system developed by our research team as an example. The system consists of four 1.5 inch \(\text{LaBr}_3\): Ce scintillation detectors. Fig. 1 shows the spectrum obtained from the environmental background of two detectors, which has the following characteristics:

![Figure 1. LaBr3: Ce spectra of Initial Spectrum of Environmental Background at 5s and 60s.](image)

1) The spectral data have three distinct zones: I, II and III. And at the boundary of the partition, the relative counting rate changes abruptly.
2) The counting rate of small size crystals is low. Furthermore, the cumulative counting is still very low in a transitory time. After smoothing the spectrum, the shape is complex and can’t be used for direct peaks searching.
3) The peak of backscattering is the most obvious in the region III and has a significant trend of change. Although the K-40 peak appears the highest probability of the junction of I and II, the peak is not obvious. In this case, automatic spectra-stabilization can be achieved unless accumulated over a long period of time.

Through the above analysis, we need to use the backscatter peak and the K-40 peak to achieve the correction of the spectrum. The key is to identify the K-40 peak position quickly. Fig.1 shows that the probability of K-40 peaks is the highest at the junction of I and II. Therefore, this method uses the reverse piecewise summation method to approach K-40 peaks one by one and extracts two
characteristic points in the backscattering region III to represent the backscattering peaks. In this way, a bimodal recognition model is established to obtain the amplitude and peak position of the eigenvalue. Then the spectrum correction is carried out by the ratio of the characteristic peak position on the target peak position.

2.1. "B&K" bimodal recognition model

The identification model of "B&K" is based on the characteristics of three partitions of spectral data. And the backscattering peaks and K-40 characteristic peaks at abrupt ratio is taken as the research objects. The recognition principle is shown in Figure 2, which mainly includes three key steps: data preprocessing, segmented peak parameter calculation and peak seeking. Firstly, the measurement spectrum data is segmented from high energy segment to low energy segment, and the change rate between adjacent segments and the peak to total ratio of each segment are calculated. Secondly, set the threshold value of peak to total ratio to eliminate false peak. Thirdly, cluster the coefficient of change rate, find out the abnormal value and get the segmentation of characteristic peak value. Finally, the eigenvalues (peak value, channel address) of the characteristic peak are obtained in the peak segmentation, and the spectrum is stabilized by software. Therefore, the specific implementation of the above process is as follows:

![Figure 2. "B&K" bimodal recognition process.](image)

1) Spectral data preprocessing

Let the total channel address of spectral data be $j$ and each channel count was represented by $a_j$. If the reverse step distance is $b$, the total number of segments are $R'$ and the total number of segments is $n = j/b$. Therefore, the spectral data $C$, the counts $R'$ of each segment and the reverse summation $S$ of the segments are expressed as follows:

$$
C = [a_1, a_2, \ldots, a_{j-1}, a_j], \\
R' = [r'_1, r'_2, \ldots, r'_{n-1}, r'_n], \\
S = [s_1, s_2, \ldots, s_{n-1}, s_n]
$$

(1)

2) Computation of peak to total and relative variation ratio

The two key parameters of the model are the peak to total and relative variation ratio. After the spectral passes through the reverse segment, there is a peak at each segment, and the false peak is eliminated by the condition of peak formation. Through experiments and knowledge of probability theory, it is found that the radiation measurement itself is a statistical event, and the objective condition for the formation of spectral peaks are that the counts of peak area regions have a larger growth probability than the non-peak region. This feature can be measured by the ratio $R$ of segment
peaks to total. And it has the possibility of local peaks when the ratio is greater than k%. So, the piecewise peak ratio and the binarization are as follows:

\[
R = [r_1, r_2, ..., r_{n-1}, r_n] = \frac{[r'_1, r'_2, ..., r'_{n-1}, r'_n]}{S_1}
\]

The peak threshold k% in upper formula needs to be paid more attention. Taking the UAV radiation detector developed by our team as an example, for the counting rate of 100 cps at 5-second, the peak forming condition is that the peak to total ratio is more than 1%.

The relative variation ratio D of subsection counts is expressed by the quotient of the difference between the counts of segment \(i+1\) and \(i\) divided by the counts of segment \(i+1\). The calculation formula is shown in (3).

\[
D = \begin{bmatrix} d_1, d_2, ..., d_i \end{bmatrix} \quad \text{for} \quad i = 1, 2, ..., n
\]

3) Peak seeking

Peak-seeking algorithm is actually a calculation method based on the characteristics of three-part spectral data. No matter what the spectral is, the peak of the backscattering is obvious, and there are two adjacent relatively large change rates after segmentation. Therefore, we first find the backscattering peak, which is expressed by two points. Secondly, we find the maximum value in the remaining relative change rate, that is, the K-40 peak position. The specific implementation algorithm is as follows:

\[
M = L \ast D
\]

\[
\text{max}(M(3:end))
\]

\[
[P, X'] = \begin{cases}
[p_1, x_1] = \text{max}(C(1:b)) \\
[p_2, x_2] = \text{max}(C(b:2 * b)) \\
[p_3, x_3] = \text{max}(C((k + 1) * b:(k + 3) * b))
\end{cases}
\]

\[
[P, X] = \begin{cases}
[p_1, p_2, p_3] \\
X = [x_1, b + x_2, (k + 1) * b + x_3]
\end{cases}
\]

2.2. GMM peak estimation

When spectral data are processed by reverse segmentation, the interval satisfying the conditions of \(L\) and \(D\) is the peak maximum probability interval. After the above treatment, it is apparent that the backscattering peaks have two relatively large change rates of \(d_1\) and \(d_2\). Therefore, we first find the backscattering peak, which is expressed by two points. Secondly, we find the maximum value in the remaining relative change rate, that is, the K-40 peak position. Next, we take the results of the peak search as the characteristic parameter and estimate the peak pattern by using the Gaussian mixture model. The formula is as follows:

\[
G = \sum_{k=1}^{3} p_k \ast \phi(y|\theta_k) \quad (k = 1, 2, 3; \theta_k = (\mu_k, \sigma_k^2))
\]

\[
\phi(y|\theta_k) = \frac{1}{\sqrt{2\pi\sigma_k}} \exp \left( -\frac{(y-\mu_k)^2}{2\sigma_k^2} \right) (\mu_k = x_k)
\]

In formula 5, \(p_k\) and \(x_k\) are the results of formula 4. And \(p_k\) is used as the amplitude parameter of GMM model and \(x_k\) as the center of the distribution [12-13]. At the same time, in order to better
match the peak, the algorithm inserts a point between the backscattering peak and K-40 peak, which constitutes a 4-point GMM peak shape estimation.

2.3. Automatic spectra-stabilization

The software automatic spectrum stabilization process is shown in Figure 3. First, the K-40 target peak is set to \(x_0\) (for example, \(x_0=512\)@1024). Then, the third point peak eigenvalue \(x_3\) is obtained through the "B&K" bimodal recognition model, which is the position of real-time K-40 peak recorded as \(x_1\). And the software gain \(G_i\) in that state is read. Finally, the ratio formula is used to calculate the next software gain adjustment [14].

So repeat the process of feature peak recognition and software gain calculation. And then write software gain \(G(i+1)\) to detector continuously until \(|m_i - m_0| \leq 1\), that is, the accuracy of spectrum stabilization is ±1 channel.

3. Simulation and results

The method of spectrum stabilization designed in this paper has been validated in the UAV energy spectrum measurement developed by our team. As shown in Figure 4, it is the main process of automatic spectrum stabilization.

Fig. 4 (a) is the 5-second spectrum measured by the LaBr3 detector. The total count of the whole spectrum is about 484. The backscatter peak is located in 50 channels, but the K-40 peak position is not obvious. Fig. 4 (d) - (f) is the "B&K" bimodal recognition process. Among them, figure 4 (d) is the spectrum after 16 segments. It can be seen that the first two segments count obviously and the third 16 segments have statistical fluctuation. Therefore, it can not be directly used to search peaks. Fig. 4 (e) shows the relative variation ratio of each segment. And the red line represents the peak threshold, which equals 1 when the total ratio of segments are greater than 1%. Finally, the backscatter peak and the K-40 peak are located in the first and the ninth segments respectively, as shown in Figure 4 (f). Therefore, the backscatter peak and K-40 peak are located in 50 and 507 channels respectively. After automatic spectrum stabilization, the 60-second cumulative spectrum of the same detector is processed the same way. So the backscatter peak and K-40 peak are located in 42 and 517 channels respectively. Moreover, the GMM peak estimation shows that the matching degree is more than 90%, as shown in Figure 4 (c).

At the same time, we validated another set of data. Fig. 5 (a) is a 5-second spectrum with a particularly low count of 475. Using this algorithm, the peak position of K-40 is 473 channels, which is 34 channels different from the actual position. The reason for this deviation is that the maximum values of the spectral lines between 450 and 550 channels are all 1. In this case, the maximum peak estimation accuracy is only related to the number of segments. The more segments, the more accurate the estimation result, which will make the calculation iterative process complex. Therefore, we can increase the cumulative time of spectral data to improve the accuracy. As shown in Figure 5 (b), when the spectrum accumulates to 10 seconds, the model can correctly find the peaks.
The above data validation shows that the method can quickly carry out spectrum stabilization. The recognition accuracy of backscatter peak and K-40 characteristic peak can be improved by adjusting the peak forming threshold and accumulation time. At the same time, the number of data segments is also an important parameter that affects the accuracy of recognition.

4. Conclusions
In this paper, the radiation measurement and the spectrum characteristics of UAV are analyzed and a fast peak identification method of "B&K" is proposed. The backscattering peak and K-40 characteristic peak can be obtained quickly by using the segmented peak to total ratio, relative counting rate and GMM estimation. This method does not need additional reference sources, does not need the smooth calculation of multiple spectra, and can automatically process in real time. Fig.6 is a
4-channel multi rotor UAV radiation measurement system developed by our team, which consists of four 1.5-inch lanthanum bromide detectors. We have verified the automatic spectrum stabilization of the system in the field environment, and the spectrum stabilization time is less than 2 minutes, and the accuracy is as high as 95%.

![Figure 6](image)

**Figure 6.** Radiation measurement system for multi-rotor UAV. It consists of four 1.5 inch LaBr3:Ce probes. The time from start-up to spectrum stabilization is less than 2 minutes.

On the other hand, this method has certain constraints. In the field environment, the instrument requires the background to be "clean", that is, the K-40 peak in the background of the environment will not be disturbed. Meanwhile, the model involves many parameters, such as relative variation ratio, peak-to-total ratio, peak forming thresholds, number of segments, standard deviation, etc. Therefore, the following research will carry out the identification accuracy under the dynamic optimization of multi parameters, and carry out the test in the actual environment.

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