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Study of different filtering techniques applied to spectra from airborne gamma spectrometry

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ABSTRACT

One of the features of the spectra obtained by airborne gamma spectrometry is the low counting statistics due to a short acquisition time (1 s) and a large source-detector distance (40 m) which leads to large statistical fluctuations. These fluctuations bring large uncertainty in radionuclide identification and determination of their respective activities from the window method recommended by the IAEA, especially for low-level radioactivity. Different types of filter could be used on spectra in order to remove these statistical fluctuations. The present work compares the results obtained with filters in terms of errors over the whole gamma energy range of the filtered spectra with the window method. These results are used to determine which filtering technique is the most suitable in combination with some method for total stripping of the spectrum.

1. Introduction

Since the beginning of 1980's, the CEA (Commissariat à l'énergie atomique et aux énergies alternatives) has been developing an airborne gamma spectrometry (AGS) system called HELINUC™ using large volume (16 L) NaI(Tl) detectors. HELINUC is used to produce radioactivity mapping of the soil. The different missions of HELINUC are:

- Research of orphan sources;
- Nuclear emergency response;
- Environmental control of radioactivity and
- International assistance.

This type of detection system is commonly employed as part of site monitoring and management of nuclear accidents (Bucher et al., 2009; Guillot, 2004,). The use of a helicopter for such measurements can quickly provide results of radiological state for a large area. Moreover, it is a simple way to access areas that are difficult to reach (mountains, forests, cities ...). For an environmental purpose, AGS is used to determine the concentration of natural isotopes (^{4}K, ^{238}U, ^{232}Th) and ^{137}Cs. By knowing the variation of the natural radiological background you can more easily detect the presence of radiological anomalies. Any brutal variation of the ^{137}Cs activity can also lead to the detection of punctual sources of ^{137}Cs.

The observed airborne gamma spectra are affected by many parameters leading to large measurement uncertainty. One of the features of the spectra obtained by airborne gamma spectrometry is the low counting statistics due to a short acquisition time (1 s) and a large source-detector distance (40 m). The statistical fluctuations lead to large uncertainties in radionuclide identification and determination of their respective activities from the window method recommended by the IAEA (IAEA, 1991), especially for low-level radioactivity.

The aim of this work is to compare different methods of reduction of the statistical fluctuations (filtering techniques) on gamma spectra. This comparison is done both with an analysis of the whole spectra and with the window method recommended by the IAEA. Previous comparison of noise reduction methods has been carried out (Hovgaard and Grasty, 1998; Mauring and Smethurst, 2005). However, these studies focused mainly on the noise reduction (Dickson and Taylor, 1998) without studying in detail the impact on the signal reconstruction.

The originality of the proposed analysis is to quantify the impact of noise filtering techniques in terms of errors on the reconstructed

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activities. This work was done using simulated spectra based on the variation of radionuclide activity of a real survey.

2. Materials and methods

The acquisition system was a detection pod attached under the helicopter, board electronics inside the helicopter, a differential GPS localization system and a navigation screen for the pilot. The detection pod contained:

- 1 pack of 16 L NaI(Tl) detector (RSX-4);
- 1 radioaltimeter for the measure of the altitude.

The NaI detectors were coupled to a 512 channel gamma-ray spectrometer. Typical energy resolutions obtained with the spectrometer were about 7% at 662 keV and about 4.5% at 2610 keV.

The noise on the reconstructed spectrum due to statistical fluctuations is the major source of uncertainty of the measurement in the case of an environmental study. These statistical fluctuations come from the Poisson nature of radioactive decay. The variation of the geometry of the sources (soil moisture, vegetation, non-radioactive overburden) and the unavoidable hypothesis on their distributions in the soil as function of the depth (volume, surface, exponential) are also an important part of the total uncertainty. Other sources of uncertainties are the concentration of radon in the air, the cosmic background, the efficiency of the detector and the air attenuation. The proposed study focused only on the statistical part of the total uncertainty.

2.1. Filtering techniques

Different filters can be used to smooth a spectrum. It is possible to classify these filters into two major categories:

- Filters based on the statistical analysis of the covariance of the spectra obtained during the flight, like the NASVD (Noise Adjusted Singular Value Decomposition) filter (Hovgaard, 1997).
- Filters which consider each spectrum independently like the local average fitting, quartic fitting, Fourier transform and Canny–Deriche smoothing (Guillot, 1996).

These different techniques are briefly described below:

2.1.1. The NASVD method

The NASVD method (Hovgaard, 1997) is based on a multivariate statistical analysis called Singular Value Decomposition (SVD). The SVD of a matrix of m spectra with n channels each, *X(mxn)*, is given by:

$$X = USV^T \tag{1}$$

Where *U(mxn)* and $V^T(nxn)$ are the column orthogonal matrices and *S* is the diagonal matrix of singular values. The eigenvectors of X^TX are the columns of *V* and the eigenvalues are the square of the elements in *S*.

For a Poisson distribution, the variance of the noise is equal to the amplitude of the signal. To perform a SVD method, the noise of all the dataset spectra must be normally distributed with an equal variance and a zero mean. This is done by fitting each spectrum by the mean spectrum of the dataset. Then, the SVD method transforms the observed spectra into orthogonal spectral components that are ordered according to their degree of contribution to the shape of the observed spectra. The spectral shape of the lower order components present correlations between channels and are interpreted as signal. The statistical fluctuations (noise) are not correlated between channels and are represented in all the spectral shapes. The noise is finally reduced by reconstructing the spectra using only the lower-order (signal-rich) components (dimension reduction). The number of components used for the reconstruction was selected by a visual inspection of these components. This visual inspection consists of the detection of signal structured shapes (same variation of counts in several adjacent channels).

2.1.2. Local average and quartic fitting method

The fit of the spectrum by a polynomial function based on the least-squares method (Blackburn, 1965) is used for these two smoothing techniques. The number of neighboring channels (2 N + 1) used to determine the value of the channel *i* is dependent on the evolution of the full-width at half maximum (FWHM) with respect to the energy. The local average (degree 0) and the quartic (degree 4) methods correspond to the product of convolution of the spectrum by a local average filter (degree 0).

$$h(t) = \frac{1}{2N+1} \tag{2}$$

a quartic filter (degree 4):

$$h(t) = \frac{15(15N^4 + 30N^3 - 35N^2 - 50N + 12)}{4(2N+5)(2N+3)(2N+1)(2N-1)(2N-3)} - \frac{35(2N^2 + 2N - 3)t^2 - 63t^4}{4(2N+5)(2N+3)(2N+1)(2N-1)(2N-3)} \tag{3}$$

2.1.3. Fourier transform method

The Fourier transform method (Cooley James and John, 1965) is based on a frequency selection of the different spectral components, i.e. the frequency variations between statistical fluctuations and real spectral information imposed by the energy resolution. In fact, the statistical fluctuations have a high frequency whereas spectral information obtained with NaI(Tl) detectors has a lower frequency. Noise reduction can also be achieved by a low pass filter that removes the highest frequencies of the spectra.

2.1.4. Canny-Deriche smoothing method

The Canny-Deriche smoothing method (Bourennane et al., 1993) is based on Gaussian form detection. The Gaussian parameters are defined from the evolution of the FWHM with respect to the energy, which is related to the detection form (S):

$$S = \frac{a}{FWHM} \times 512 \tag{4}$$

2.2. Simulation framework

We performed a Monte-Carlo simulation of the experimental setup based on MCNPX software (Pelowitz et al., 2011). The simulation was used to obtain well-defined spectra for ^{137}Cs, ^{4}K, ^{238}U, ^{232}Th (and ^{60}Co for 4.3) based on experimental data obtained from a baseline survey realized over Albertville-Le Villard, flown by the CEA in October 2011. This site has been used for about 10 years as a calibration site and is radiologically well characterized. The parameters of this survey are given in Table 1.

The acquisition time of each spectrum was 1 s. This short acquisition time was needed to have a good spatial resolution to detect brutal variation of activity. This time is the reference acquisition time for the HELINUC system.