



Noise reduction of PGNAA spectrum using empirical mode decomposition technique

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ABSTRACT

Prompt gamma neutron activation analysis (PGNAA) is frequently used in on-line analysis of raw materials in cement and coal industries which normally incorporates bismuth germanate (BGO) or sodium iodide (NaI(Tl)) scintillators. The quantitative results are basically undertaken through full-spectrum analysis method which requires an efficient noise reduction procedure to optimize PGNAA data. Here in this study, the empirical mode decomposition (EMD) technique has been used to reduce the noise level of PGNAA spectra of a neutron-irradiated NaCl-H₂O solution and then the results have been compared with those of wavelet technique. The mean square errors (MSEs) comparisons confirm that both EMD and wavelet techniques can be efficiently used for noise reduction purposes, however, this study recommends the EMD technique for its independency of basic functions, simplicity and spectrum data-based operation.

1. Introduction

PGNAA has been extensively used in various applications such as explosive and drug identifications in passenger luggage, landmine detection, separation of chemical from non-chemical explosives in old remnants of wars, cement and coal industries, etc. (Oden et al., 2006; Charbucinski et al., 2003; Lim and Abernethy, 2005; Gozani and Strellis, 2007; Bergaoui et al., 2014). The PGNAA gamma ray spectrum may be analyzed either through peak search or full spectrum. The peak search method is generally implemented in case of high-resolution detector such as high-purity germanium (HPGe) where the qualitative and quantitative studies are undertaken according to the position and area under a specific peak. The full-spectrum method, on the other hand, is popular in case of relatively poor-resolution detectors such as BGO or NaI(Tl) scintillators (Ghal-Eh et al., 2016). In full-spectrum method, the gamma-ray spectra corresponding to specific amounts of all elements of interest are obtained either through measurement or simulation to form spectrum libraries. Then the unknown sample spectrum which is assumed to be a linear superposition of library spectra is unfolded with one of the several mathematical methods such as least-squares (Gardner and Xu, 2009), fixed-point iterations (Akkurt, 2002), artificial neural networks (Doostmohammadi et al.,

2010), etc., leading to quantitative and qualitative elemental data.

This analysis method has been commonly used in commercial PGNAA systems such as those used in on-line coal and cement raw material analysis. The full-spectrum analysis is unfortunately an inverse-problem type in which there may be numerous solutions for a single input condition. An inverse problem is actually the process of calculating the causal factors of a set of observations (e.g., calculating an image in X-ray computed tomography from detectors data). It is called an inverse problem because it starts with the results and then calculates the causes. This is the inverse of a forward problem, which starts with the causes and then calculates the results (Tarantola, 2005).

Therefore, in order to improve the precision of this method, one has to reduce the noise in gamma ray spectrum in addition to appropriate boundary condition determination. The gamma ray spectrum noise may be attributed mainly to low counting statistics which is itself due to short spectroscopy time, low detection efficiency at high-energy region of spectrum (e.g., 10.8 MeV nitrogen peak) or the small sample activity. The statistical noise of gamma ray spectrum normally decreases after a very long acquisition time but since this is not applicable in most cases one has to use computational methods for filtration and noise reduction. Filtration for noise reduction is used in many science and engineering disciplines. Well known filtration techniques such as FT,

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STFT, wavelet and PCA depending on signal characteristics (i.e., stationary or non-stationary, linearity or non-linearity, etc.) may be used in time, frequency or time–frequency domains.

Since the PGNA spectrum is of non-stationary nature, there are very limited number of noise reduction techniques (e.g., wavelet) proposed for this purpose (Barzilov et al., 2015). Although the wavelet method represents a relatively appropriate time–frequency resolution, the choice of basic function determines the accuracy of this method which is not always an easy task (Martis et al., 2011; Singh and Tiwari, 2006).

The EMD technique was first presented by Huang in 1998 (Huang et al., 1998). The validity of this method in non-stationary and even non-linear signal analysis has been proved. EMD is totally adaptive and data driven and it does not require basic function selection. In this method, a non-stationary non-linear signal is decomposed into a stationary linear component of intrinsic mode function (IMF) together with a remainder (i.e., a constant value or signal trend) such that the original signal can be completely reconstructed with these components. Therefore, high-frequency components (i.e., noise) can be simply discriminated from main data (Boudraa et al., 2007; Tsolis and Xenos, 2011). The EMD techniques has been used in signal analysis and classification as well as noise reduction in biomedical engineering, seismology, mechanical engineering, optics, etc. (Colominas et al., 2014; Rojas et al., 2013; Su et al., 2010; Wang et al., 2012; Yin et al., 2015).

In this research, EMD has been used for the noise reduction of an NaI(Tl) spectrum when exposed to prompt gamma rays of a neutron-activated sample. The results have been compared with wavelet output data to show the feasibility of the proposed method.

2. Materials and methods

2.1. PGNA measurement setup

The prompt gamma spectrum of a neutron-activated sample has been measured with a portable PGNA tool as shown in Fig. 1. The setup has been located at 95 cm and 200 cm distances from the laboratory ground and surrounding walls, respectively. The setup consists of a 10 mCi ^{252}Cf neutron source, a Scionix 3-inch by 3-inch right cylinder NaI(Tl) scintillator, a NIM-standard spectroscopy electronics and appropriate detector shielding.

The shielding consisting 18.5 cm iron followed by 31.5 cm high-density polyethylene (HDPE) has been constructed in such a way that the thermal neutron fluence at sample position is optimized (Bayat et al., 2016). In order to suppress the background count rate, the NaI(Tl) detector has been placed inside a 2.5 cm thick lead shield. The sample has been 400 g NaCl dissolved in 4 l H_2O .

The gamma-ray spectra has been measured with a 13-bit (or equivalently, 8192-channel) analog-to-digital convertor (ADC) to intentionally enhance the noise contribution.

The noisy and reference PGNA spectra of the sample have been measured in 600 s and 15 h, respectively. In order to balance the spectroscopy time with the contribution of delayed gamma rays originating from sample, detector and shielding elements, the long

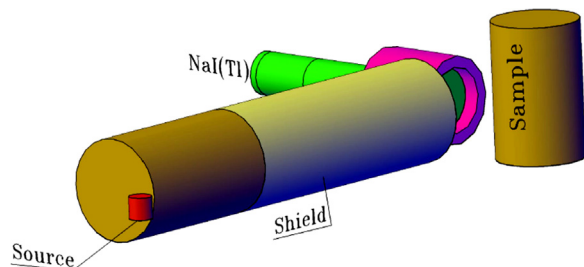


Fig. 1. Schematics of a portable PGNA measurement system.

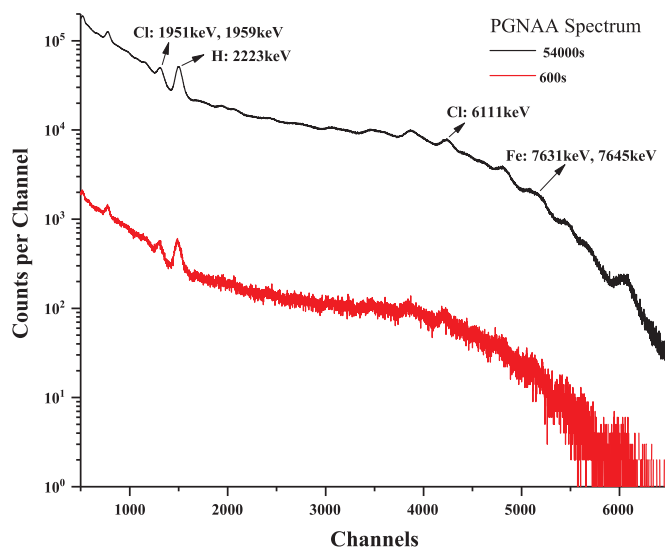


Fig. 2. Neutron-activated prompt (and delayed) gamma rays spectra of $\text{NaCl.H}_2\text{O}$ solution measured in two different live times (600 s and 15 h).

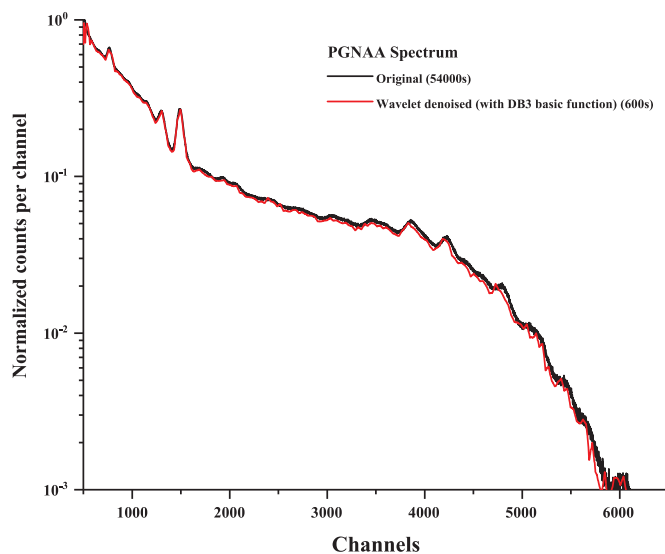


Fig. 3. Comparison between denoised prompt gamma ray spectrum using wavelet method (with DB3 basic function) and reference spectrum.

acquisition has been undertaken prior to the short one. The low-amplitude pulse height region of PGNA spectrum includes many peaks associated with prompt and delayed characteristic gamma rays, as well as single- and double-escape peaks corresponding to higher-energy gammas. The background gamma-rays, almost all Compton continua, backscattering peaks, electronic noise and the dark current of photo-multiplier tube (PMT), etc. also contribute in small pulse height region. This clearly causes a high counting rate and consequently large dead time.

This pulse-height region of PGNA spectrum would not provide useful information if poor resolution detectors such as NaI(Tl) scintillator are used which is due to many peak overlaps. This also perturbs the full spectrum analysis such that a small variation in high-energy region would not result in an observable effect which weakens the analysis sensitivity. In full spectrum analysis, depending on the elemental characteristic gamma rays, the low pulse-height region is omitted as much as possible. In this research, the PGNA spectrum of neutron-activated $\text{NaCl.H}_2\text{O}$ solution below 700 keV is omitted because the sodium and chlorine characteristic gamma rays are (1368 keV, 2027 keV, 2754 keV, ...) and (789 keV, 1164 keV, 1951 keV, 1959 keV,

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