Chapter 7

Assessment of Gamma-Ray-Spectra Analysis Method Utilizing the Fireworks Algorithm for Various Error Measures

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ABSTRACT

The analysis of measured data plays a significant role in enhancing nuclear nonproliferation mainly by inferring the presence of patterns associated with special nuclear materials. Among various types of measurements, gamma-ray spectra is the widest utilized type of data in nonproliferation applications. In this chapter, a method that employs the fireworks algorithm (FWA) for analyzing gamma-ray spectra aiming at detecting gamma signatures is presented. In particular, FWA is utilized to fit a set of known signatures to a measured spectrum by optimizing an objective function, where non-zero coefficients express the detected signatures. FWA is tested on a set of experimentally obtained measurements optimizing various objective functions—MSE, RMSE, Theil-2, MAE, MAPE, MAP—with results exhibiting its potential in providing highly accurate and precise signature detection. Furthermore, FWA is benchmarked against genetic algorithms and multiple linear regression, showing its superiority over those algorithms regarding precision with respect to MAE, MAPE, and MAP measures.

INTRODUCTION

Globalization, and the viability of the interstate system upon which it rests, crucially depend on international security that includes nuclear security, safeguards and nonproliferation. This is more true today than any other time since 1648 when the Treaty of Westphalia gave birth to the modern notion of interstate system (Mock, 2011). Besides the apocalyptic specter of nuclear war, failure to check nuclear proliferation may lead to chaotic instabilities and a global system in rapid and irreversible decline, especially in view of the devastating effects of nuclear and radiological weaponry on urban communities (Alamaniotis et al., 2013). Lack of effective nuclear security may very well unleash forces of disintegration and decay in the modern global system. Thus, nonproliferation treaty enforcement is of paramount importance (Bunn, 2003).

Nonproliferation is an area within the field of nuclear security that highly relies on interdisciplinary knowledge culminating in precise analysis of measurements in order to detect and identify the use, storage and transport of special nuclear materials (SNM) (Runkle et al., 2010). To that end, data and information analysis aiming at detecting and identifying patterns of interest is one of the cornerstones in nuclear nonproliferation (Alamaniotis et al., 2015). Data collection refers to the process of collecting information, content and contributions from various radiological and non-radiological sources. However, the most common (i.e., widest used) type of data in nonproliferation is the gamma spectroscopic measurements. Analysis of gamma spectroscopic measurements is performed with specialized algorithms that seek for patterns of interest in the obtained measurements (Burr & Hamada, 2009). Gamma-ray measurements are obtained in the form of energy spectra, where a single spectrum is the aggregation of contributions coming from various sources. It should be noted, that a gamma-ray spectrum also contains contribution from materials of the ambient environment; this contribution is known as "background spectrum" (Alamaniotis et al., 2013a). Therefore, the variety of contributions increase the complexity of the gamma-ray spectrum, and as a result, low contributed sources may be masked by high contributed ones.

Analysis of gamma-ray spectra aims at identifying the constituents of a measured spectrum. On one hand, several analysis algorithms seek to extract features that may be utilized for identification of the spectrum constituents. On the other hand, a high number of algorithms focus on utilizing the whole spectral curve instead of extracting features. Following the latter approach, a common strategy in gamma-ray spectrum analysis is the fitting of the measured spectrum with a set of predetermined spectra, which are obtained either through measurements or simulations (Tsoulfanidis & Landsberger, 2013).

In this chapter, the focal point is the analysis of gamma-ray spectra into their constituents by adopting a fitting process. The fitting process is conducted by formulating an optimization problem whose solution is sought by the Fireworks Algorithm (Tan & Zhu, 2010). It should be noted that spectrum fitting denotes the minimization of the distance between the linear combination of available signature patterns and the measured signal (Hogan et al., 1970). The goal of fitting is to analyze the measurement into those constituents whose synthesis best matches the initial measurement. Notably, in nonproliferation applications there is no prior information about the contents of the spectrum. In other words, the measured spectrum is considered as totally "unknown". The degree of fitting (i.e., distance) is expressed quantitively as the value of a measure (i.e., error) function between the linear combination and the measured signal (Tsoulfanidis & Landsberger, 2013). The signatures with statistically significant non-zero coefficients are indicated as the final list of constituents in the measured spectrum.

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