Development of Empirical Mode Decomposition based signal improvement method and its implementation on Pulse Shape Analysis for a segmented HPGe detector

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Introduction

The concept of Next-Generation of gamma ray spectrometers will offer high gamma-ray detection efficiency while maintaining the spectrum quality to investigate the structural properties of nuclei far away from the line of stability. The future detector arrays such as AGATA/GRETA [1] would provide the 4π solid angle coverage around the target having composite assembly of HPGe detectors with high granularity. Therefore, they adds new concept of γ-ray detection by finding out its position of interaction within the active volume of the Germanium detector. Hence, in addition to energy and timing information, the detectors also provide the position information of the triggered event. The position of the detected event in the detector volume can be reconstructed in three dimension by highly efficient Pulse Shape Analysis (PSA) algorithms. These algorithms can be implemented on the given pulse shape resulting in the ensemble of position co-ordinates along with all the information regarding energy deposition, interaction position, energy and position resolution. The Gamma-Ray Tracking (GRT) algorithms can be implemented on the position co-ordinates to reconstruct the incident gamma-ray energy as well as its emission angle with respect to source. Therefore, PSA plays a key role to improve the detector performance. The PSA of a two fold clover detector has been investigated under a new signal enhancement algorithm based on Empirical Mode Decomposition technique. The Geant4 based detector simulation studies has also been performed.

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Empirical Mode Decomposition technique

Empirical Mode Decomposition (EMD) is a standard technique developed by Huang *et al.* [2] to analyse linear, nonlinear, chaotic, stationary and non-stationary types of signals. The technique decomposes the given time series into a series of components each having characteristic behaviour in phase space with proper phase structure and frequency, known as Intrinsic Mode Functions (IMFs) [2]. The IMFs are defined as the functions with symmetric envelopes and carry zero local mean value such that there is dyadic decrease in number of zero crossings of each decomposed symmetric envelopes across the modes [3]. The instantaneous frequency of the components can be obtained from the Hilbert transformation in the local timescale of the IMF [2]. Each of the IMF carries the embedded oscillations in the time series, such that the superposition of the IMFs construct the original signal $X(t)$ as:

$$X(t) = \sum_{i=1}^{i=r} IMF_i + C \qquad (1)$$

where r is the total number of IMFs and C is the corresponding residue left from the process known as sifting process. The IMFs of the decomposed signal can be treated as equivalent filters [3] as they capture the dynamics of the system at different time scales.

EMD based algorithm development

The theoretical algorithm has been developed based on EMD for noise reduction of different types of theoretical (linear, nonlinear and choatic signals) and experimental signals (Astrophysical, Neutron detector) for the investigation of PSA [4] [5] [6]. The proposed filtering approach is based on the frequency distribution of different Intrinsic Mode Functions (IMFs). It provides complete frequency and noise strength information present in the data set. The identification of noise structure and enhanced signal reconstruction is based on the correlation coefficient calculation performed in both frequency as well as in time domain. The investigation of the algorithm on different types of theoretical signals with simulated noise levels has been carried out. Further, investigation on the experimental signal reveals the performance of the method with good signatures [4].

Application of the algorithm on the Pulse Shape Analysis of a two fold clover HPGe detector

A two fold clover detector (available at TIFR, Mumbai) has been used to study the implications of the algorithms for PSA [6] [7]. The outer contact of each crystal of the detector is segmented longitudinally to further divide each crystal electrically into two segments. There are four energy signals delivered from the inner contact, one from each crystal. Besides the four energy signals from the crystals, there are three additional energy signals available from the detector. The detector pulse shapes are recorded with a standard GSI Multi-Branch data acquisition system for the investigation of the EMD based algorithm. A C++ Object-Oriented based analysis software has been developed under Go4 (GSI Object-Oriented Online-Off-line) framework to investigate PSA. In the software a dedicated class for EMD technique along with the proposed algorithm has been implemented on to analyse the data on event-by-event basis. The application of the algorithm on mirror signal provides a reconstructed signal along with the decoupled IMFs responsible for the noise. It has been observed that the algorithm produces shift in mean mirror amplitude distribution at each scanning position and predicts different centroid values of noise strength distribution across the scanning surface of a two fold clover detector [6].

Geant4 based simulation studies

The Geant4 based simulation code has been developed to study the position response along with pulse height information of a two fold clover detector. The simulated energy events are generated and compared with the experimental events with good agreement [6]. A Gamma-ray Tracking code is developed to utilize the mapped events for studying the imaging performance of the detector using a simple Compton back-projection method. The simulated position response are used to generate the experimental Compton images at different positions for ^{137}Co and ^{60}Co sources. The experimental position resolutions of the Compton images produced in X and Y Co-ordinates for the localized sources (^{137}Cs, ^{60}Co) are determined under different gamma-ray energies and Compton background [6].

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