

# Novel automated method for offline correction of data affected by time instability

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## Abstract

A new method has been developed with the aim to correct measured shape-changing spectra for sudden shifts due to instability of the detectors' electronics in time. The automated method is based on the discrete cross-correlation. Potential of this method has been tested on experimental decay and in-beam  $\gamma$ -ray spectroscopy data and respective spectra measured with the array of three n-type coaxial High-Purity Germanium detectors.

## Introduction

Time instability of a detector's processing electronics can have drastic influence on the collected data, especially if the measurement runs for more than one day or even a week. It is not exceptional to observe relatively slow, or in some cases even sudden changes in energy gain and offset. These changes in the measured spectra are often observed as gradual deterioration of the peak's shape and FWHM with increasing energy. At higher energies, a split of a peak into two separated peaks in the same spectrum may occur. As such data can distort the results, they should be omitted in the data analysis. This inevitably leads to decreasing a statistics in the spectra. To prevent data loss, appropriate corrections need to be applied on such datasets.

A manual off-line correction requires isolation of each shift in the measured data. Thus, a set of test spectra is created and corrected with their respective shift and gain parameters. However, in some cases, the shift is so frequent and chaotic that making manual corrections to spectra is not feasible anymore. The use of an automated method is then a necessity.

The automated method proposed by Palacz *et al.* [1] uses the total-spectrum fitting approach in calculation of the correction parameters. It is only applicable on spectra that do not change their shape in time. This requirement is a limiting factor for many experiments, *e.g* decay and in-beam  $\gamma$ -ray spectroscopic studies with varying reaction rate.

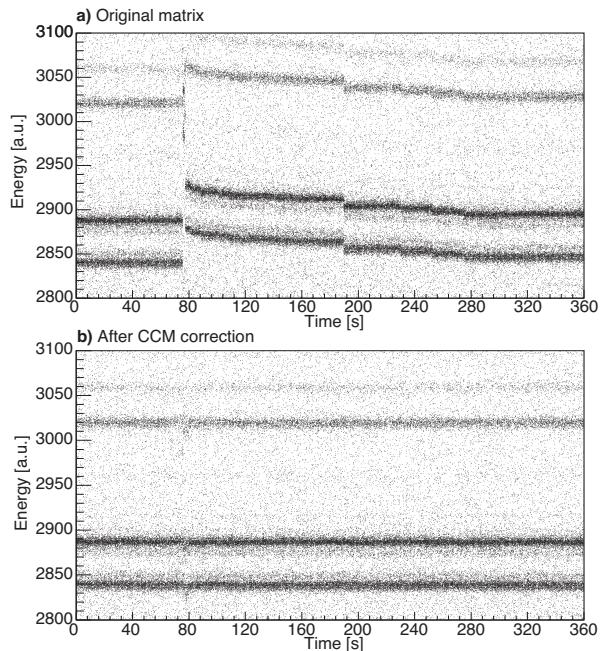


Figure 1: Sample of the  $\gamma$  rays measured with the n-type GMX 70P4-95 coaxial HPGe detector in the Material research laboratory in Trnava, Slovakia. Panel a) demonstrates the detector's time instability and its effect on the measured data, while panel b) shows the same data after the CCM correction.

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In the present work, we introduce new automated method for off-line correction of the time instability called the Cross-correlation Correction Method.

### The Cross-correlation Correction

Unlike the method by Palacz *et al.* [1], the Cross-Correlation Correction Method (CCM) can also be applied on shape-varying spectra. The use of the CCM is conditional on the presence of at least one shape-stable region in the test spectrum, *i.e.* it contains either a peak or another recognisable feature ideally from the natural background.

To demonstrate a capability of this new method, the CCM algorithm has been applied on the data measured in the long-term experiment with a duration of 3 months. The experiment was carried out at the Material research laboratory of the Slovak University of Technology in Trnava, Slovakia [2]. In the experiment, a thick  $^{nat}\text{Ni}$  foil was bombarded with a  $^4\text{He}^{2+}$  beam, accelerated to an energy of 8.2 MeV by the Tandetron accelerator. The reaction products were studied by means of the  $\gamma$ -ray spectroscopy. The fully digitised array of three n-type GMX 70P4-95 coaxial High-Purity Germanium (HPGe) detectors was used to detect prompt and delayed  $\gamma$  rays. Detectors were instrumented with the XIA Pixie-16 Digital Gamma Finder module. The digital data acquisition system was operated in the triggerless total data readout mode and data were analysed offline.

During the experiment, time-instability of one of the HPGe detectors was recorded. In Fig. 1, a part of the relevant data is displayed in the time-energy matrix (a) before, and (b) after correction using the CCM.

### Algorithm

The data are first sorted into the time-energy matrix. A set of test spectra is created from single time-bin projections onto energy axis. Correction parameters are to be individually found for each test spectrum. One test spectrum is always chosen as a reference for correction (the so-called reference spectrum). If possible, the reference spectrum should be selected from a time-stable region. In order to improve statistical precision, the reference spectrum can also be created as a sum of multiple time-stable test spectra.

Subsequently, one or multiple narrow energy regions (further denoted as regions of interest - ROIs) are selected in order to calculate relative displacement between the reference and the test spectra in a given energy region. Selected ROIs must contain a peak or peak

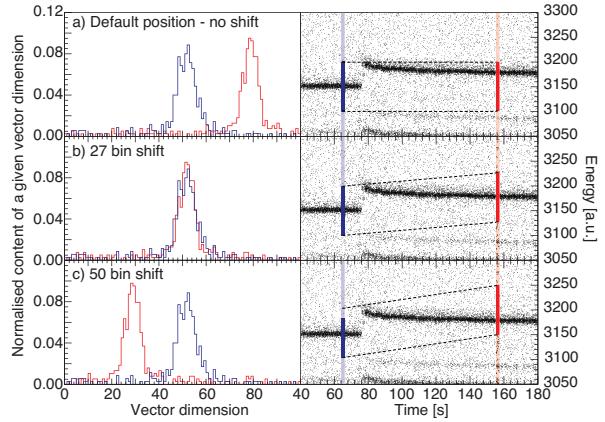


Figure 2: (Colour online) Illustration of the discrete cross correlation method applied on the  $\gamma$ -ray time-energy matrix in search for a relative displacement between the reference (red) and the test spectra (blue). Panels on the right highlight the area of energy projections with given time-width in light colours, from which 100 bins are selected, normalised and treated as vectors, as shown in respective on the left-side panels (reference vector in blue, test vector in red). The selection of bins for the test vector is gradually shifting to allow computation of dot product of reference and test vectors as a function of the test vector displacement.

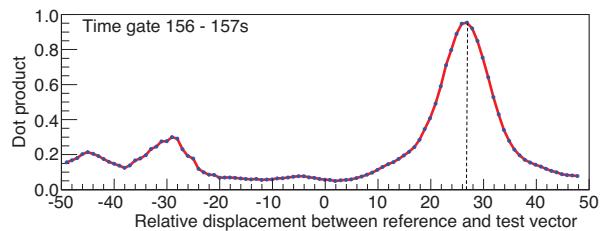


Figure 3: Graph showing the evolution of a dot product between test and reference vectors as function of the relative displacement between the reference and the test vectors. Dot product set for the reference and test spectra shown in Fig. 2 is presented. Presence of neighbouring peaks which can also be seen in the time-energy matrix in Fig. 2 is evident for relative displacement of -28 and -45, but a shape similarity with reference vector is low.

multiplets, scattering peaks etc. with sufficient statistics. The relative displacement is determined based on their relative similarity using the discrete cross-correlation. Selected ROIs of the test and the reference spectra are formally treated as N-dimensional vectors in Euclidean space with their mutual angle  $\phi$ . The angle between two vectors is by definition a good measure of their similarity. Once the two vectors are normalised, their dot product is equal to  $\cos(\phi)$ , giving values in the range of (0,1). A set of dot products is calculated by displacing the test vector. This is done by gradually redefining its energy bounds, as illustrated in Figs. 2 and 3. Finally, a relative displacement between the test and reference spectra in a given ROI is determined by identifying a maximum from the calculated dot products. Alternatively, a quadratic function can be used to fit multiple dot product values around the maxima, and the relative displacement is then identified as the maximum of the quadratic fit. This allows to achieve a decimal number precision as oppose to integer values of displacements that are given by energy binning. Energy of the ROI matching the relative displacement is calculated from the reference spectra as a mean energy weighted by a bin content.

Correction parameters for a test spectrum are determined by fitting the values of relative displacement of all ROIs as a function of their energy. Selection of a fitting function is arbitrary, but a simple linear fit was found to be sufficient. Its selection is only restricted by number of fitting points, *i.e.* number of ROIs.

Precision of the CCM depends on the nature of the time distortions and on the selection of the ROIs. It comes as no surprise that if the distortions are evolving faster than the data are collected, the data cannot be reliably corrected. This is shown in Fig. 1 around 80 s mark. However, this holds true for any algorithm working only with time and energy information. Fortunately, rapid distortions of this type are rather infrequent and of limited duration (in the data available to the authors), and affected events can therefore be omitted without significant decrease of statistics.

The ROIs should have statistics high enough for a fine time-slicing of the time-energy matrix. The ROIs should be focused on regions which are most affected by energy shifts. Since the correction of the time instability is usually a matter of gain and offset adjustment for individual test spectra, this translates into demand for intensive peak or spectral feature with high energy.

To evaluate an achieved precision of the CCM, the FWHM values of the peaks in corrected spectrum should be extracted. Optimal ROIs, energy binning and width of time slices can then be found by identifying the

minimum FWHM of the set of peaks from a series of the CCM runs, see Fig. 4. The monitored peaks should be among the most affected ones by the time instability, whilst not used as a reference region in the CCM to avoid over-fitting.

Further improvements of the presented algorithm could utilise uneven time-binning and creation of time-overlapping test spectra resulting in even spline-like application of corrections. However, this was not persuaded in present work, as the CCM was found to provide accurate results when applied on present datasets.

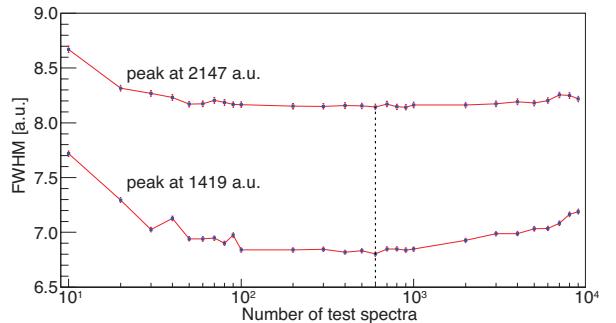


Figure 4: Search for ideal number of test spectra, *i.e.* time-width of test spectra. In case of present data, the FWHM minimum was found for slicing time-energy matrix into 600 test spectra, which is equal to the 2.3 s time-width for each test spectrum. Note, that the FWHM value for the original uncorrected spectrum is not included, as it contains partially or fully detached peaks due to time instability. Thus, the FWHM is not a good tool for its evaluation.

#### *Application in decay spectroscopy*

In this section, we present application of the CCM on the decay spectroscopy data. The data come from the same experiment as above, but the emitted  $\gamma$  rays were measured when the beam was off. Although this dataset was as well affected by the time instability, gain and offset shifts were not as vivid as those shown in Fig. 1. For a better visualisation and test of the CCM performance, the collected data were artificially distorted by reverse application of correction coefficients obtained from a different experiment. Moreover, distortions to data were also partially randomised. Part of the artificially distorted data is shown in Fig. 5.

Gain correction was obtained with the CCM by using two ROIs: one containing natural background peak at an energy of 1460 a.u and second ROI contained peak at an energy of 660 a.u. coming from radioactive decay of the irradiated target. This was done to test the CCM performance on the shape varying ROI and compare it with the original data and with the CCM corrected spectrum applied on the time-stable region. Comparison of the

corrected spectra is shown in Fig. 6. The CCM applied on decaying ROI performed slightly worse, but this can be at least partially ascribed to the rather low energy of the ROI.

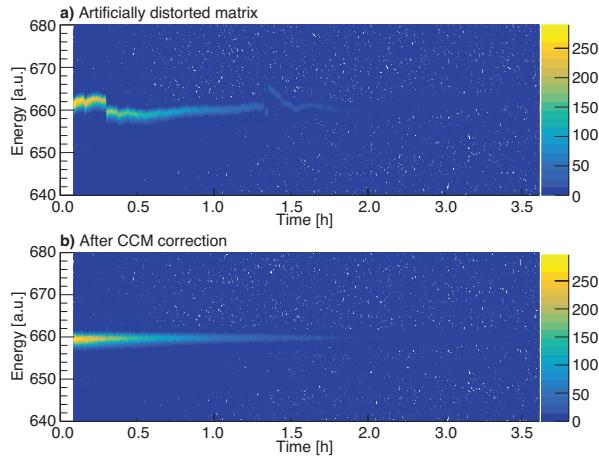


Figure 5: (Colour online) Panel **a**) shows the  $\gamma$ -ray time-energy matrix with artificially distorted data used to test the CCM performance on shape-evolving energy regions. Panel **b**) displays the same matrix after the CCM correction.

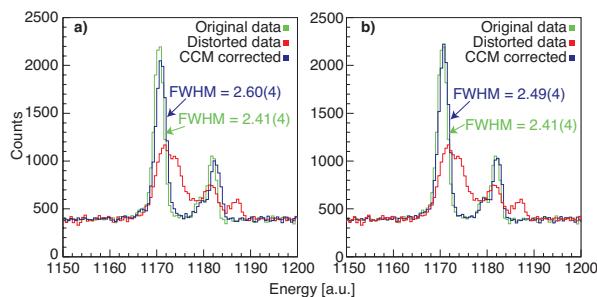


Figure 6: (Colour online) Original spectrum (green) shown together with artificially distorted spectrum (red), and the CCM corrected spectra (blue). The CCM corrected spectrum shown in panel **a**) used for correction of a single ROI placed around  $\gamma$ -ray peak from radioactive decay at an energy 660 a.u. ROI of the corrected spectrum in panel **b**) was set around  $\gamma$ -ray peak from room background radiation at 1460 a.u.

## Conclusion

A new algorithm based on the cross-correlation corrections has been developed to correct measured spectra for sudden energy shifts caused by time-instability of the detector's electronics. Performance of the algorithm was tested on both the in-beam  $\gamma$ -ray spectroscopy data and artificially distorted decay spectroscopy data including a randomising parameter with a great success.

The Cross-Correlation Correction Method has proven itself to be a powerful tool to fix the effect of the unstable behaviour of coaxial High-Purity Germanium detectors on the measured spectra. Other types of radiation and detectors have not yet been tested due to lack of appropriate data. The CCM can also be used for energy calibration of high number of similar-type detectors. Such a use is especially useful for in-beam  $\gamma$ -ray spectrometers (*e.g.* JUROGAM, AGATA, GRETINA etc.), or channels of the same detector.

The C++ code used in present work is available at <https://github.com/matLogh/CCM> together with example datasets.

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