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#6-24 Comparative analysis of automatic identification of radionuclide in gamma-ray spectrometry: machine learning versus statistical approaches

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Gamma-spectrometry is a widely used technique for identifying and quantifying gamma-emitting radionuclides in many nuclear applications such as rapid identification to prevent illegal trafficking of nuclear materials, decommissioning of nuclear facilities or in situ environmental analysis following a radiological or nuclear accident. For many years, there has been a growing trend to address the problem of automatic identification of gamma-emitting radionuclides by implementing Machine Learning (ML) approaches such as the multilayer perceptron or the convolutional neural network (CNN). This method is an end-to-end ML that uses a large training data set of different radionuclide mixtures. It is used as a black box, so the physical property such as Poisson noise or the linear nature of the mixture model is not explicitly taken into account. Besides this approach, the statistical method based on full-spectrum analysis with Poisson likelihood gives solid results. This method decomposes the observed spectrum into individual characteristic energy spectra depending on the decay scheme of each radionuclide (called spectral signatures) and employs the Maximum likelihood estimator (MLE) and statistical tests to identify radionuclides, quantify and calculate the uncertainty of the estimated counting. This study compares the identification performances of the ML and MLE approaches in three scenarios: firstly, spectral signatures are assumed to be known, corresponding to well-defined measurement conditions; secondly, spectral signatures are deformed due to physical phenomena such as Compton scattering and attenuation; and thirdly, spectral signatures are shifted due to factors like temperature changes. A large dataset of 200000 simulated spectra was generated for each case, varying the number of radionuclides present in the source, statistical levels, and mixing weights. A dictionary of spectral signatures of nine radionuclides (^{57}Co, ^{60}Co, ^{99m}Tc, ^{123}I, ^{131}I, ^{133}Ba, ^{137}Cs, ^{152}Eu and ^{241}Am) and an experimental natural background is investigated in this work. The spectral signatures were simulated using the Monte Carlo code Geant4 for a 3"×3" NaI(Tl) detector. Regarding the ML approach, recent studies have shown that, among all the ML methods available in the gamma-ray spectrometry literature, CNN gives the best results and is therefore used in this work. In the current literature, radionuclide identification can be treated as a multi-label or binary classification problem in ML. This work integrates these two ML approaches by fine-tuning the various hyperparameters of the CNN, such as the number of layers, the learning rate, the number of filters, etc. Concerning the statistical approach, for the case of spectral deformation, a hybrid approach combining ML to model spectral signatures with variability and MLE, as well as statistical hypothesis testing, is applied. Numerical results show that the statistical approach outperforms the ML approaches for three tested scenarios in terms of accuracy and also has the ability to control the false alarm rate close to the predefined value, which is not possible for ML methods. However, the performance of this approach can be significantly reduced when spectral signatures are not modeled correctly. Thus, the full-spectrum statistical approach is most effective where spectral signatures are assumed to be known, corresponding to well-defined measurement conditions, or where spectral variability can be modeled. In other cases, where measurement conditions are not well-defined or difficult to model, end-to-end ML is a suitable alternative.

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