Autoencoder Latent Representations and One-Dimensional Convolutional Neural Networks for the Identification of Composite Radioisotopes

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Abstract:

Reliable isotope identification from short, low-count γ-ray spectra is critical for security and environmental monitoring, However field spectra suffer from background and instrumental effects. We present two models for the classification of mixed isotopes: (1) Autoencoder and (ii) a one-dimensional convolutional neural network (1D-CNN) that learns spectral features directly from the 1024-channel input spectrum. Training uses simulated NaI(Tl) spectra spanning source–detector distances and counting times. Robustness is tested on held-out sets with mismatched conditions, including calibration shifts unseen during training. Results show both approaches achieve high accuracy on matched conditions, but the autoencoder-based model provides more stable evidence and better generalization under varying calibration, outperforming the 1D-CNN in disturbed settings.

Introduction

Accurate and rapid identification of radioisotopes from γ-ray spectra is essential for security, environmental monitoring, and emergency response [1]. Field spectra are low-count, and distorted by shielding, calibration drift, and gain variations, which severely degrade the performance of traditional peak identification and energy-library matching methods [1].Data-driven models that learn from full spectra can exhibit more stable performance against overlapping peaks and calibration/gain drift [2].Deep learning approaches such as CNNs using gain/calibration augmentation and channel-attention mechanisms improve accuracy, but because the models are large, they require very substantial training data, making these methods complex to train [3,4].

Methodology

Training and testing data are synthesized with simulation using a 2″×2″ NaI(Tl) detector. We consider six isotopes (Co-60, Cs-137, I-131, Ba-133, Am-241, Tc-99m), eleven source detector distances (1–100 cm), and six acquisition times (30–180 s), producing mixed-nuclide and low-count conditions.
An example of simulated spectra with high and low counts is shown in Figure 1.

Results and Discussion

Across increasing isotope counts and under peak broadening, the autoencoder sustains a more favorable precision–recall trade-off than the smoothed 1D-CNN, yielding higher F1 at greater mixture complexity. These results indicate that the autoencoder preserves discriminative structure that remains robust as peaks widen and overlap.
In Fig. 2, the smoothed 1D-CNN's recall degrades rapidly as additional isotopes are introduced—particularly within the ±10–20% window—leading to an early drop in F1. By contrast, the autoencoder's curves are flatter: precision increases with isotope count while recall declines more gradually. In Fig. 3, peak broadening harms both models, yet the smoothed 1D-CNN again shows a steeper decline in recall and F1 as mixtures grow more complex. The autoencoder maintains a more balanced precision–recall.

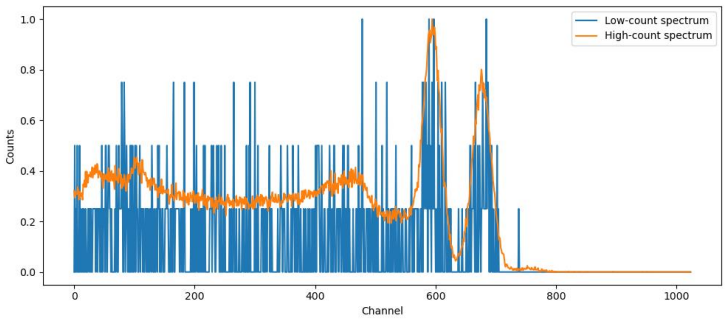

Figure 1 shows the simulated spectra with high and low counts.

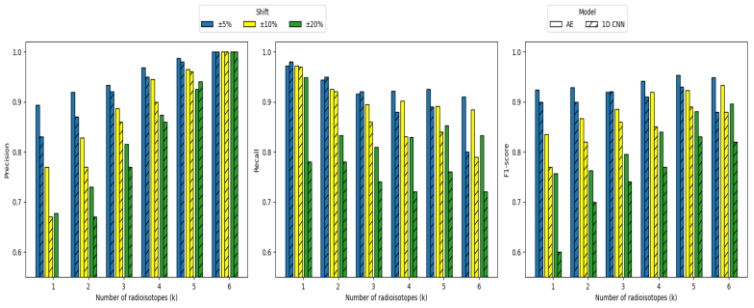

Figure2. Performance under uniform calibration shifts

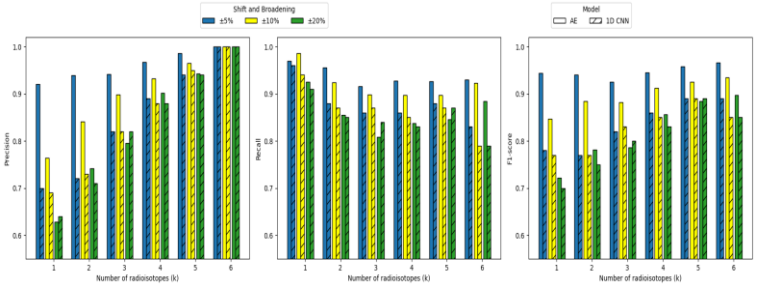

Figure3. Performance under energy-resolution degradation.

Conclusions

Based on the results, the autoencoder model learns meaningful structures and patterns which, under various conditions, deliver higher accuracy and stability than a one-dimensional convolutional neural network (1D-CNN). This efficiency and performance make it practical for field deployment in nuclear security, environmental monitoring, nonproliferation verification, and emergency response.

References

[1] Zhang, S., Marsden, E., & Goulermas, J. Y. (2022). Isotope identification using artificial neural network ensembles and bin-ratios. IEEE Transactions on Nuclear Science, 69(6), 1194-1202.
[2] Galib, S. M., Bhowmik, P. K., Avachat, A. V., & Lee, H. K. (2021). A comparative study of machine learning methods for automated identification of radioisotopes using NaI gamma-ray spectra. Nuclear Engineering and Technology, 53(12), 4072-4079.
[3] Khatiwada, A., Klasky, M., Lombardi, M., Matheny, J., & Mohan, A. (2023). Machine Learning technique for isotopic determination of radioisotopes using HPGe γ-ray spectra. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 1054, 168409.
[4] Sullivan, C. J., & Stinnett, J. (2015). Validation of a Bayesian-based isotope identification algorithm. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 784, 298-305.

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