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Deep Learning-Based Approach for Real-Time Radioisotope Identification: A Novel 1D CNN Model and Experimental Validation

Real-time radioisotope identification (RID) is an indispensable application in many critical areas, from environmental monitoring to national nuclear security. However, challenges posed by field conditions, such as the limited energy resolution of commonly used scintillation detectors like NaI(Tl), low counts, natural background radiation, and shielding, adversely affect the automatic identification process. Simple algorithms and library-matching methods, which have been used and developed for many years, are highly inadequate, especially in cases of mixed isotopes and calibration drift. This creates an urgent need for consistent and efficient machine learning-based algorithms that can learn complex patterns from spectrum data and perform identification with higher accuracy, capable of correctly classifying even mixed radioisotopes. In this article, a novel one-dimensional CNN architecture is presented for the purpose of classifying gamma spectra containing combinations of five different radioisotopes (Eu-152, Co-60, Am-241, Ba-133, Cs-137). As a result of experiments conducted for optimization, a four-block architecture was used. It includes strided convolution for dimensionality reduction, 50% dense dropout regularization, problem-adapted 5 and 7-dimensional kernels in the first block, and an increasing number of filters (from 32/64 to 256/512). The dataset, enriched with 8 different distances for linear and logarithmic scaled data obtained from Monte Carlo simulations, FPGA, and oscilloscope-based experimental systems, was meticulously evaluated with 10-fold cross-validation. The optimized CNN architecture has proven its effectiveness by demonstrating superior success in classifying mixed radioisotopes with an approximate F1-score of 0.994. This study, which also analyzes the training/testing times on different graphics cards (A100, L4, T4) and the effects of parameter optimization, shows that deep learning architectures tailored to the specific problem can yield groundbreaking results in the field of automatic RID. In this context, the best performance was achieved with the A100, completing the training in approximately 20.2 seconds. On the other hand, regarding test times, although the L4 graphics card (0.211 sec) showed high performance close to the T4 (0.201 sec), the A100 provided the best performance at 0.212 seconds.

Keywords: Radioisotope Identification (RID), Deep Learning, Convolutional Neural Networks (CNN), Gamma-Ray Spectroscopy, Mixed Isotopes

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