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Online Classification of Diverse Metal Materials Using PGNAA and Machine Learning

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Recycling scrap as secondary raw material in Europe is not only the safest but also the most sustainable and economically viable source of raw materials. This option remains available despite political conflicts with mining countries. Moreover, engaging in recycling minimizes or avoids conflicts between the local population and the mining industry, particularly concerning human rights issues in those countries. Given the substantial and diverse mass flows in copper and aluminum production, there is a significant interest in real-time classification of recycling materials.

We present an approach that has enabled non-destructive online analysis of heterogeneous materials for the first time and is currently in use. This method relies on Prompt Gamma Neutron Activation Analysis (PGNAA), showing potential for non-destructive material analysis. The challenge in using PGNAA for online classification arises from limited and noisy data due to short-term measurements. Traditional evaluation methods, such as detailed peak-by-peak analysis, prove ineffective. To address the chalange, we suggest treating spectral data as probability distributions, enabling material classification through maximum log-likelihood.

For classification purposes, a fully measured spectrum is obtained for each material, and a kernel density estimator generates the corresponding probability distribution. Using the maximum (log-)likelihood method, unknown short-time measurements are assigned to materials based on the best-fitting distribution of a fully measured spectrum. This approach requires only a single fully measured spectrum for material classification, allowing for online classification without data preprocessing and additional training data.

The distribution can also be used to generate training, test, or validation data through sampling. This allows quick and easy generation of any number of spectra from a single source. Depending on the random sample size, simulation of short measurement times is flexible, eliminating the need for costly new data acquisition. Additionally, the generated data is crucial for parameter estimation of the kernel density estimator and the training of convolutional neural networks.

Experimental data includes 5 aluminum alloys, 5 copper alloys, and a total of 11 different materials (aluminum, cement, copper, E-scrap, stucco, soil, batteries, ore, melamine, PVC, and ASILIKOS). For pure aluminum alloys, near-perfect classification is achieved in under 0.25 seconds. To highlight the ease of classifying different materials, the measurement time is reduced to 0.0625 seconds, resulting in 100% correct classification.

Comparing our method with a Convolutional Neural Network (CNN), commonly used in spectrum classification, we demonstrate that our approach allows faster classification. Additionally, we employ Class Activation Maps (CAM) to visualize relevant spectrum areas during classification.

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