AI-Based Online Spectral Classification of Copper Alloys using PGNAA

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Introduction

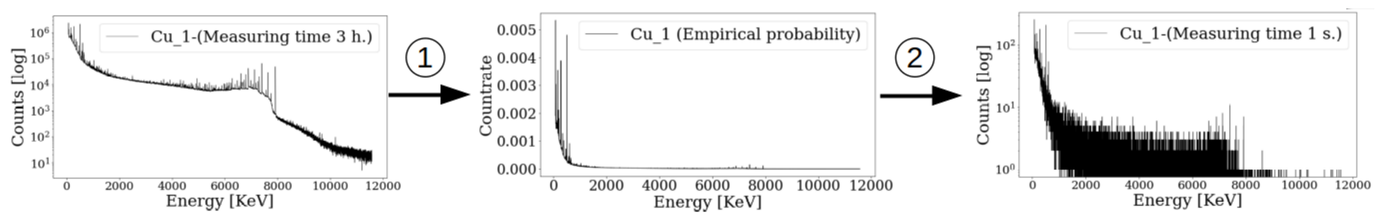
- Recycling processes gain importance due to environmental, economic sustainability, and political considerations.
- We address the novel challenge of non-destructively classification of mixed copper alloys.
- We will use Prompt Gamma Neutron Activation Analysis (PGNAA) and a High Purity Germanium (HPGe) sensor for non-destructive material analysis.
- Three classification methods: Maximum log-likelihood (MaxLogL), Neural Network (NN), Convolutional Neural Network (CNN).
- We have demonstrated that the CNN exhibits significantly superior classification performance for copper alloys compared to the current state-of-the-art in CNNs.
- We demonstrate the feasibility of online classification for blends of multiple copper alloys, achieving near-perfect results in less than one second of measurement time.

Method

Data (measurement time 3 hours)
Our results are based on mixtures of copper alloys and proportions are displayed in the table:

66% Cu1 + 33% Cu3	50% Cu1 + 50% Cu3	66% Cu2 + 33% Cu3	33% Cu1+33% Cu2+33% Cu3	50% Cu1 + 50% Cu2
33% Cu2 + 66% Cu3	50% Cu2 + 50% Cu3	33% Cu1 + 66% Cu2	66% Cu1 + 33% Cu2	33% Cu1 + 66% Cu3

Data generation



① From a thoroughly (3 hours) measured copper alloy, obtain the empirical probability, by dividing the count rate of a specific energy value by the total count rate.

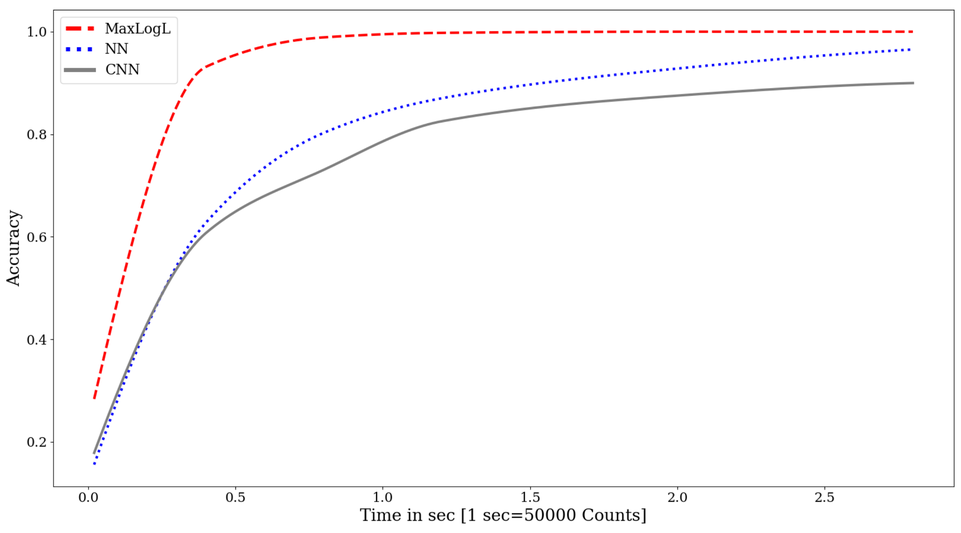
② Sample short-time measurements (e.g., 1 s) from this distribution.

Data classification

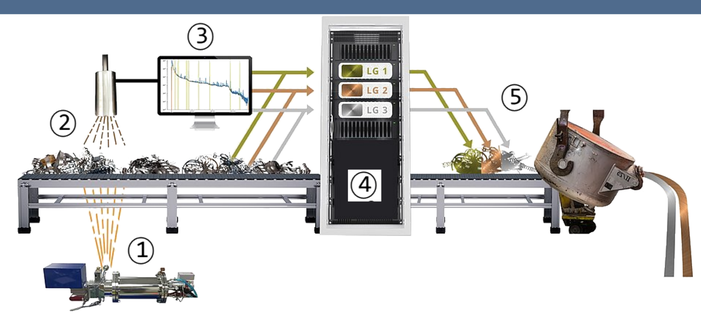
- To assign an unknown short time measurement to a material, we compare three methods: MaxLogL, NN, and CNN. All methods utilize the whole information of the spectrum and not only estimated peaks.
- The maximum log-likelihood method assigns the short-time measurement to the most fitting distribution of a fully measured spectrum.
- The NN has 13 hidden layers, while the CNN has four convolutional layers, ReLU activation, and max-pooling, ending with a fully connected layer. Both models were trained using CrossEntropyLoss, with a learning rate of 0.01 for NN and 0.001 for CNN, and Adam optimizer over 150 epochs.

Result

- The figure presents a comparison of accuracy over time for MaxLogL, NN, and CNN.
- Achieve an impressive accuracy of 95.76% within a quarter of the counts, i.e., 25,000 counts (0.5 seconds), using maximum log-likelihood.
- MaxLogL achieves better accuracy than NN and CNN.



The overall process



① The scrap is irradiated with a beam of neutrons.

② Through nuclear reaction, the material emits prompt gamma rays, which are measured with a gamma ray spectrometer.

③ The data of measured gamma spectra can be saved/visualized and

④ classified using an algorithm.

⑤ After classification, the material can be recycled purposefully.

Conclusion

- The goal of online classification of mixed copper alloys with use of PGNAA in less than one second of measurement time can be achieved with maximum log-likelihood.
- Highlighted possibility of distinguishing between mixed materials, even with similar alloys.
- The goal of online classification of mixed copper alloys in less than one second of measurement time can be achieved with maximum log-likelihood.
- Improved CNN classification of copper alloys with better classification rate in one-fifth of the time compared to existing benchmarks.
- NN performs better than CNN, and maximum log-likelihood produces the best result.

FRN

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