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Analyzing radioxenon spectra with machine learning algorithms to predict Activity Concentration of Each Isotope

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ABSTRACT

In this study, we aim to develop a new approach using machine learning and data mining algorithms to estimate the activity concentration of radioxenon isotopes of any unknown sample from calibrated raw spectra without adhering to extensive mathematical calculations. So far, several methods have been applied to estimate net counts for each isotope such as the region-of-interest (ROI) and the simultaneous decomposition analysis tool (SDAT). By means of machine learning methods, we specifically analyse Beta–Gamma coincidence spectra in the format of real two-dimensional raw spectra which are not sensitive to gain shifts in the detector's energy calibration. Our purpose is to improve MDC in the detection of low-level activity concentration of radioxenon isotopes.

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INTRODUCTION

- Comprehensive Nuclear-Test-Ban Treaty (CTBT) aims to detect and prevent nuclear tests all around the world.
- Only radioactive gases can be released into the atmosphere through dynamic venting or atmospheric pumping.
- Most of the isotopes are short-lived and will decay shortly after production into other elements.
- Four radioxenon isotopes are long-lived enough to be relevant for verification purposes.
- Several radioxenon systems have been developed for supporting the collection, purifying, and counting of the four CTBT relevant of xenon.
- For the categorization of the radioxenon events, the activity concentration is one of the most important quantities providing information on whether there was detection of an isotope and at which confidence.

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INTRODUCTION

- The current analysis approach for calculating the radioxenon activity concentrations is based on determining the net counts for each isotope using a region-of-interest (ROI).
- Another approach is utilizing simultaneous deconvolution (SDAT) through fitting a sample with standard spectra. The standard spectra are detector response functions, which include the four radioxenon isotopes plus radon. These spectra or templates are combined together and used to determine the optimal contribution of each to provide the best fit to the sample.
- Recent progress in artificial intelligence is largely attributed to the rapid development of machine learning, especially neural network models.
- In this work, the validity of machine learning used to calculate the concentration of each isotope in a sample is investigated.

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METHODS

Input data:

The dataset was derived from AUX09 measurement station between 2019 and 2020. We extracted 2D beta-gamma coincidence spectra and respective activity concentrations.

Data preprocessing:

- To feed data into the regression model, we linked each sample with its respective activity concentration and gas background by using the same sample ID using python programming.
- Spectra with category ‘A’ were excluded from training the model for faster analysis as they consist of radioxenon isotopes with concentrations less than the critical limit.
- We used the total of 1400 samples from which 607 samples were level ‘B’ and ‘C’.
- 2D histograms of spectra were projected to one of the axes of gamma and beta.

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METHODS

Model:

- The ML method is supervised, inputs are the projected 2D energy spectra, and outputs are known radioxenon isotope concentrations.
- Training set includes the 70% of entire dataset and 30% is assigned to the test set.
- A multi-output regressor model was applied using the Linear Support Vector Regression (LSVR) for predicting concentrations. Also, Multi Layer Perceptron (MLP) model for regression is trained and tested.
- Two performance metrics were derived: the mean absolute error (MAE) and the mean squared error (MSE) to compare predicted and actual values.

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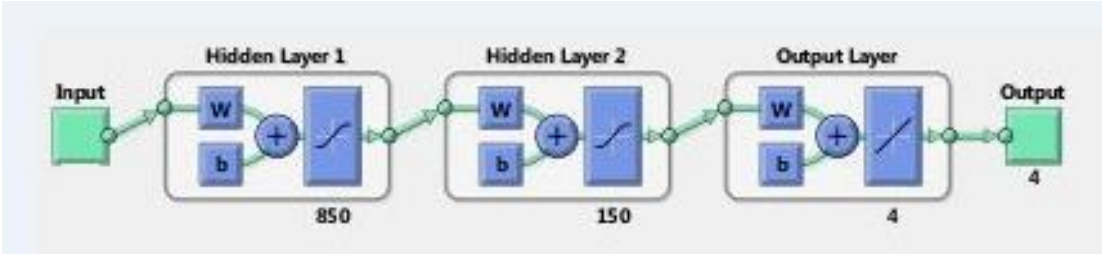
RESULTS

Preliminary results

Linear SVR					
Isotopes	Xe131m	Xe133m	Xe133	Xe135	All isotopes
MAE (mBq/m3)	0.045	0.035	0.077	0.185	0.088
Error	0.009	0.012	0.016	0.037	0.014

MLP	
MSE (mBq/m3)	0.002
Error	0.0043



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CONCLUSIONS

- ✓ Our model was trained with experimental data derived from detectors included backgrounds, Radon and so on.
- ✓ This study shows that machine learning perspective can be applied to identify each radioxenon isotopes in each spectrum and quantify the respective activity concentrations.

Future work:

We will test several models and algorithms for generating the optimized solution with lower error and more reliability when predicting activity concentrations of each radioxenon isotopes.