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RAISE
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Multi-Radioisotope Identification Using Convolutional Neural Networks Trained with Two-Dimensionally Transformed Gamma Spectrum Data Measured Using a CsI(TI) Spectrometer

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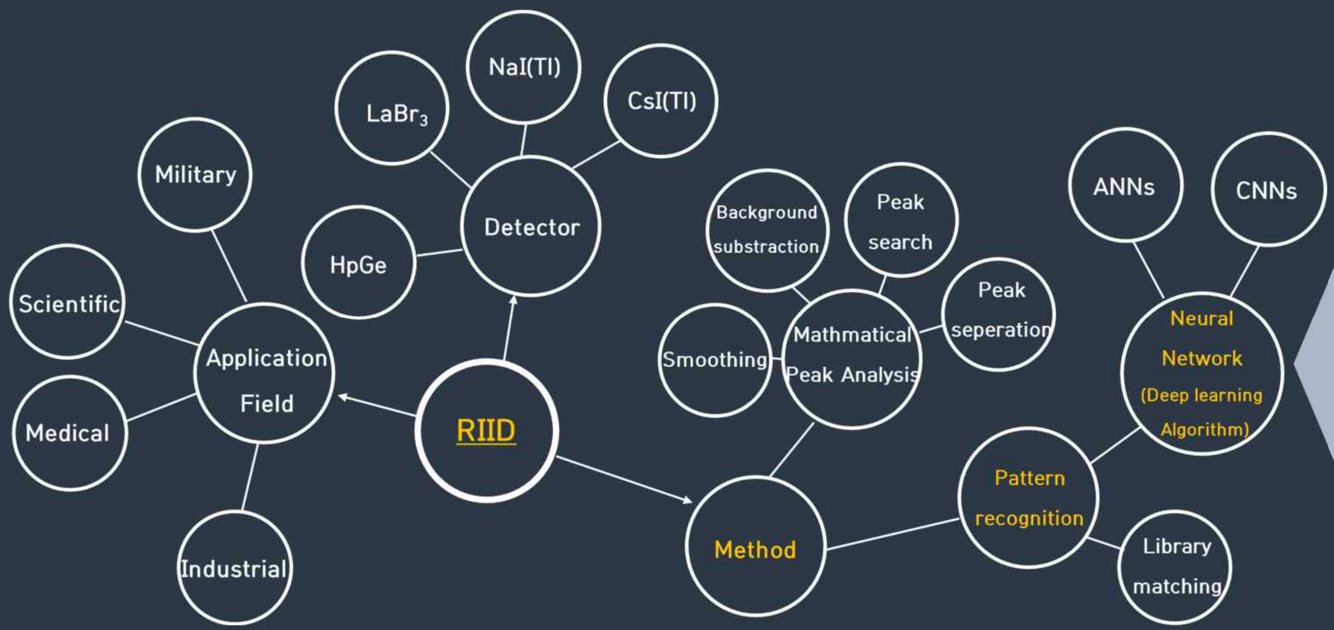
Contents

Radioisotope Identification (RIID) ?

- Quantification or identification of the radioactive materials in Gamma-ray spectroscopy

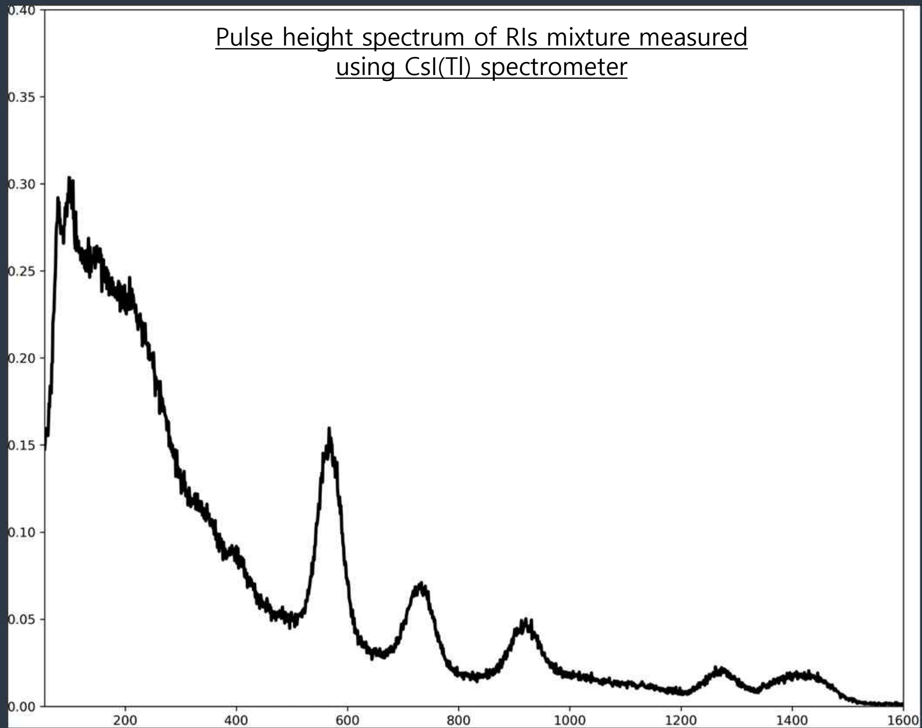


Neural Networks for RIID

- **Energy Calibration X**
- **Unfolding X**
  (Unfolding : Smoothing, Background substraction, Peak search, Peak separation, etc)
- **High Accuracy & Efficiency**
- **Multi-isotopes Identification**
  (good resolving power for overlapped peaks)
- **Powerful when using low-resolution detectors (NaI, CsI(Tl), etc)**

Neural Networks for RIID

How many Radioisotopes(RIs) can be identified in this spectrum?



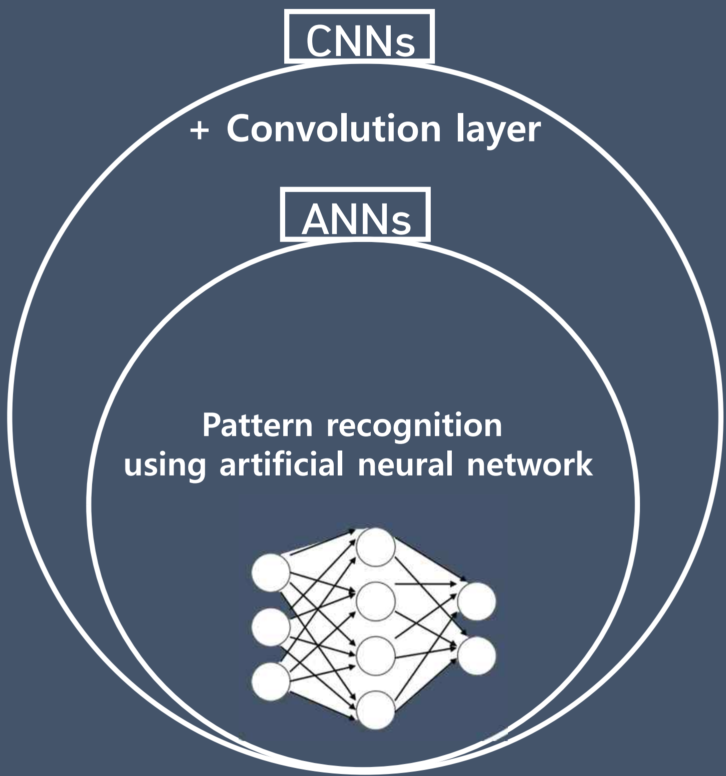
-> ^{241}Am, ^{57}Co, ^{137}Cs, ^{60}Co, ^{22}Na, ^{133}Ba, ^{109}Cd, and ^{54}Mn can be identified and quantified relatively within 4~5% error when using Convolutional Neural Networks.

Neural Networks for RIID

- CNNs* and ANNs** commonly are used for RIID of Gamma-ray spectroscopy

*CNNs: Convolutional Neural Networks, **ANNs : Artificial Neural Networks (called NNs or FC-NN)

ANNs vs CNNs



ANNs

- Each neuron in one layer is fully connected to all neurons in the next layer
  - → Numeber of training parameters ↑
  - → Overtraining, overfitting ↑
  - → Training time ↑

CNNs

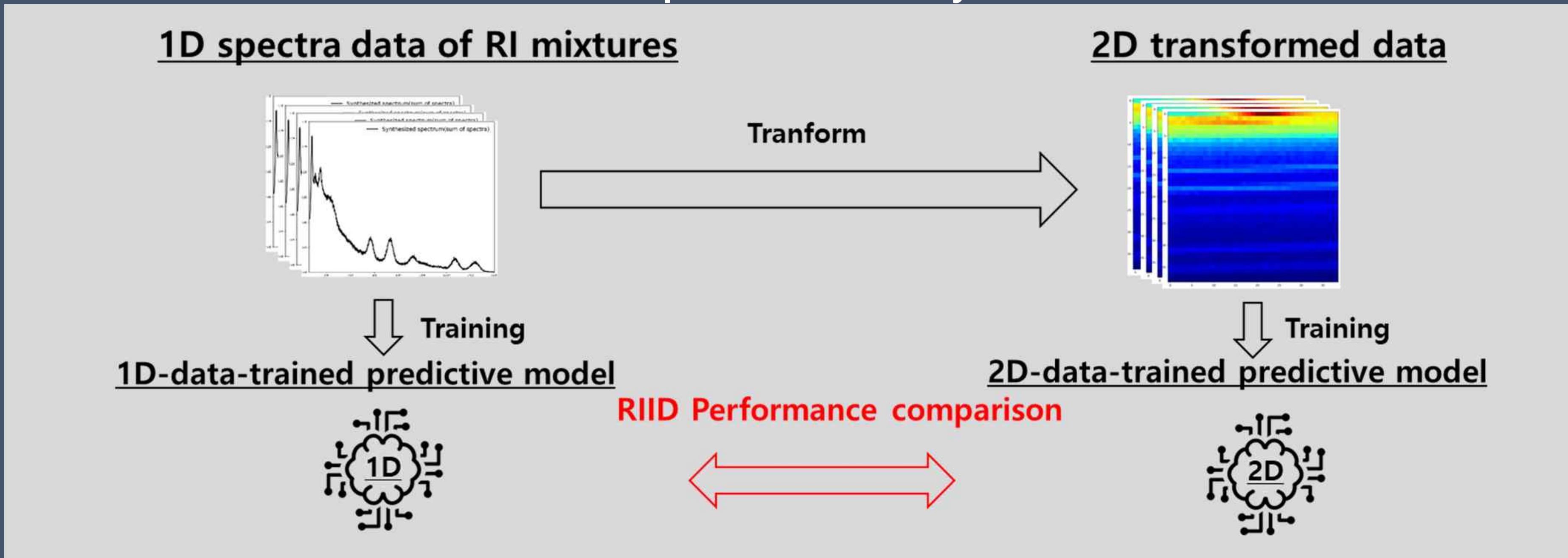
- Fewer parameters owing to the weight sharing and sparse connectivity through convolutions
  - → Numeber of training parameters ↓
  - → Overtraining, overfitting ↓
  - → Training time ↓
  - → High efficiency & accuracy for RIID
  - → Important 'features'(such photopeaks, Compton edge) are localised

CNNs More applicable for RIID & Needed to be developed more

Purpose of the study

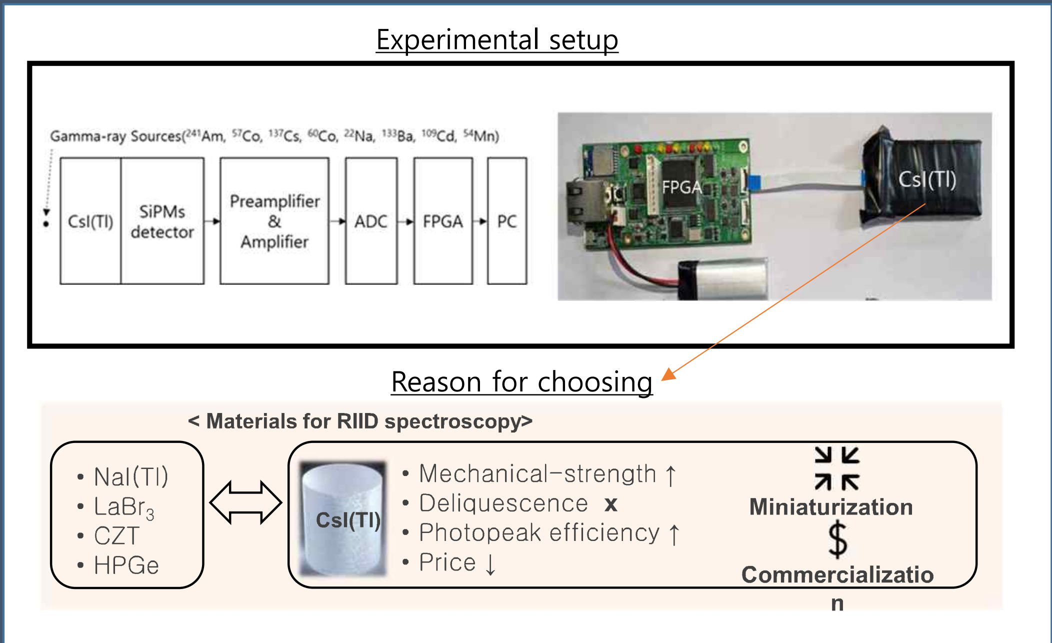
- For the development of CNNs for RIID, We use 2D transformed input data of RI mixtures for training of CNN model rather than use typical 1D spectrum data of RI mixtures.
- We compare the RIID performance of CNN models trained with 1D spectra and the transformed 2D inputs

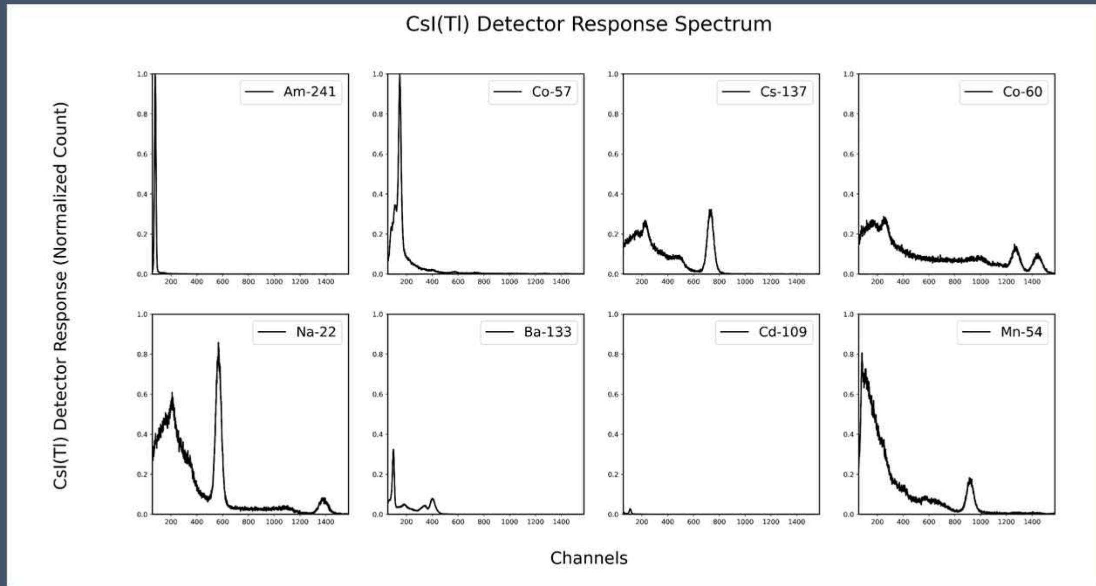
Purpose of this study



Experimental setup

- The experimental setup to measure the energy spectrum to be used for learning of CNNs
- CsI(Tl) crystal is coupled to silicon photomultipliers(SiPMs)
- Eight gamma-ray sources (^{241}Am, ^{57}Co, ^{137}Cs, ^{60}Co, ^{22}Na, ^{133}Ba, ^{109}Cd, and ^{54}Mn) used for generating single RI spectrum





Pulse height spectra of single RIs measured using the CsI(Tl) spectrometer

1D spectrum data generation

- Datasets are generated through data synthesis of the spectra.

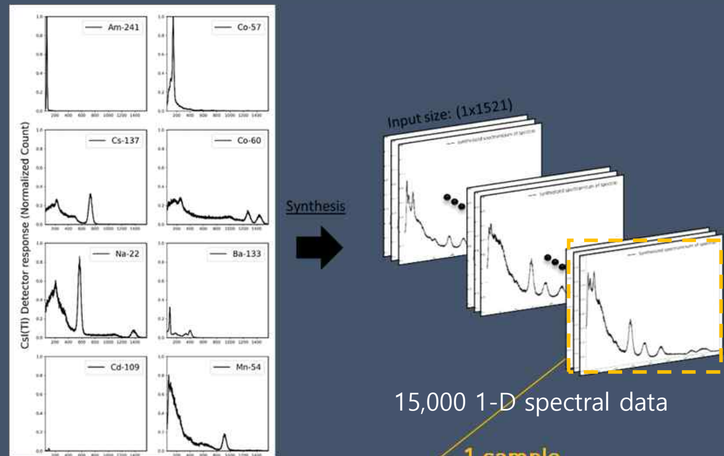
1. Pulse height spectra s_j of single RI j are normalized to one
2. Each spectrum with 4096 channels is constructed to a spectrum wi th 1521 channels by discarding unnecessary front (noise: ~55) and rear (empty: ~1576) channel sections
3. Normalized spectrum s_j' of single RI j is multiplied by the synthesi s coefficient c(0~1) that is randomly determined
4. Synthesized artificial spectrum S can be expressed as a linear com bination with the coefficient

$$S_i(x) = \sum_{j=1}^{N} c_{ji}\ s_j'(x)\ \left(\sum_j^N c_{ji} = 1\right)$$

N : the total number of RIs, 8

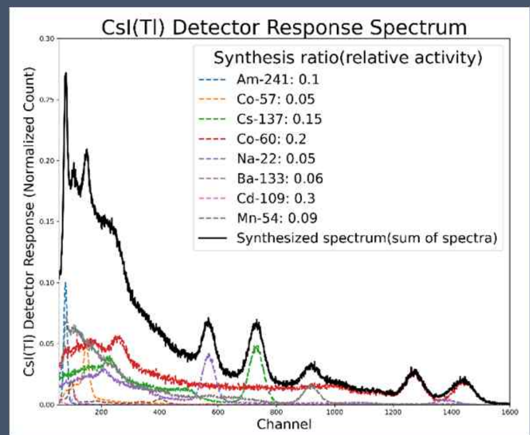
c_{ji} : synthesis coefficient (relative activity) of RI j for the ith random generation(i : 1 ~ 15,000)

- 15,000 1D spectral data for multiple radiation sources in various ratios can be generated.



15,000 1-D spectral data

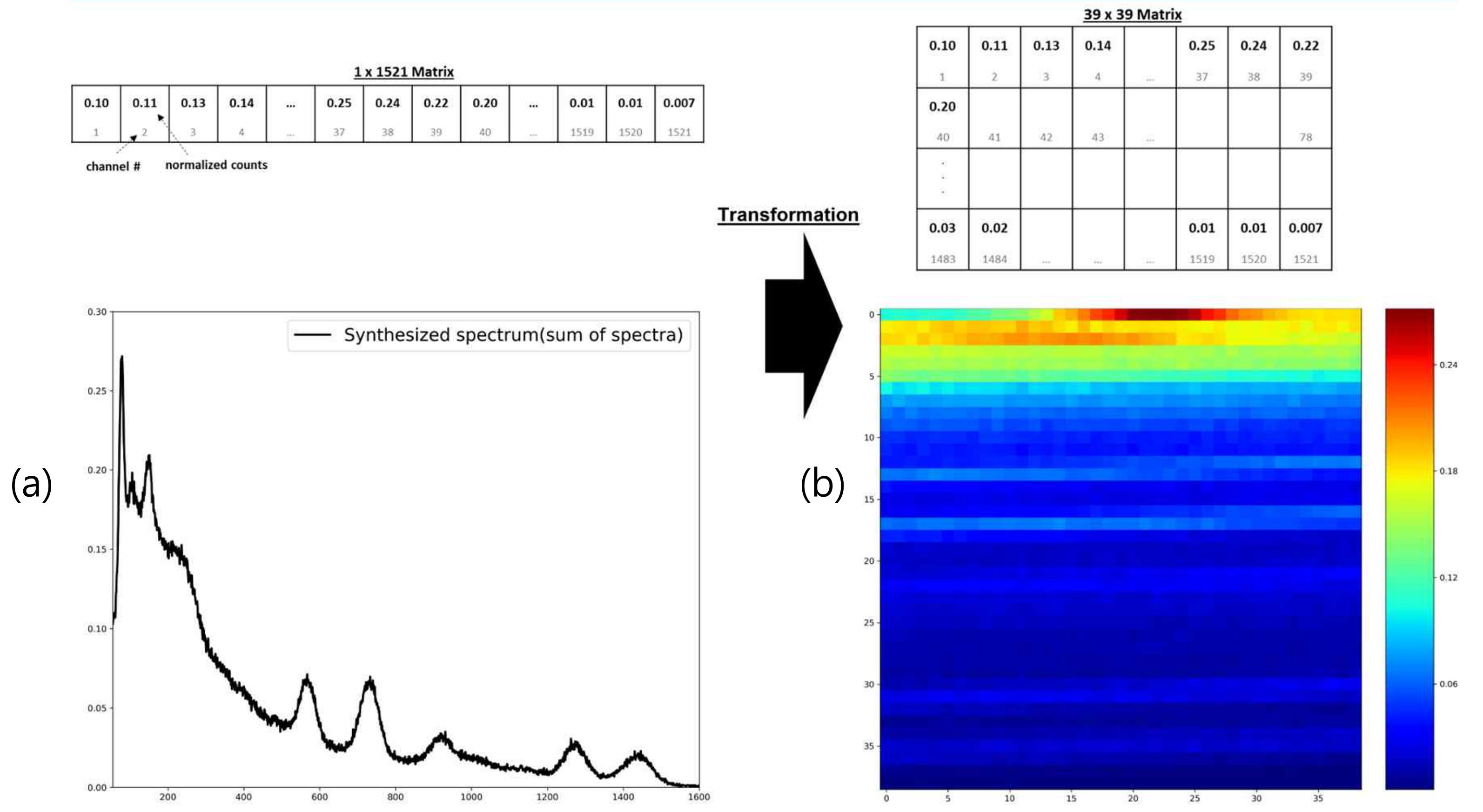
1 sample



An example of th spectra of different RIs at various relative radioactivity levels and the synthesized spectrum of multiple RIs

2D transformed data generation

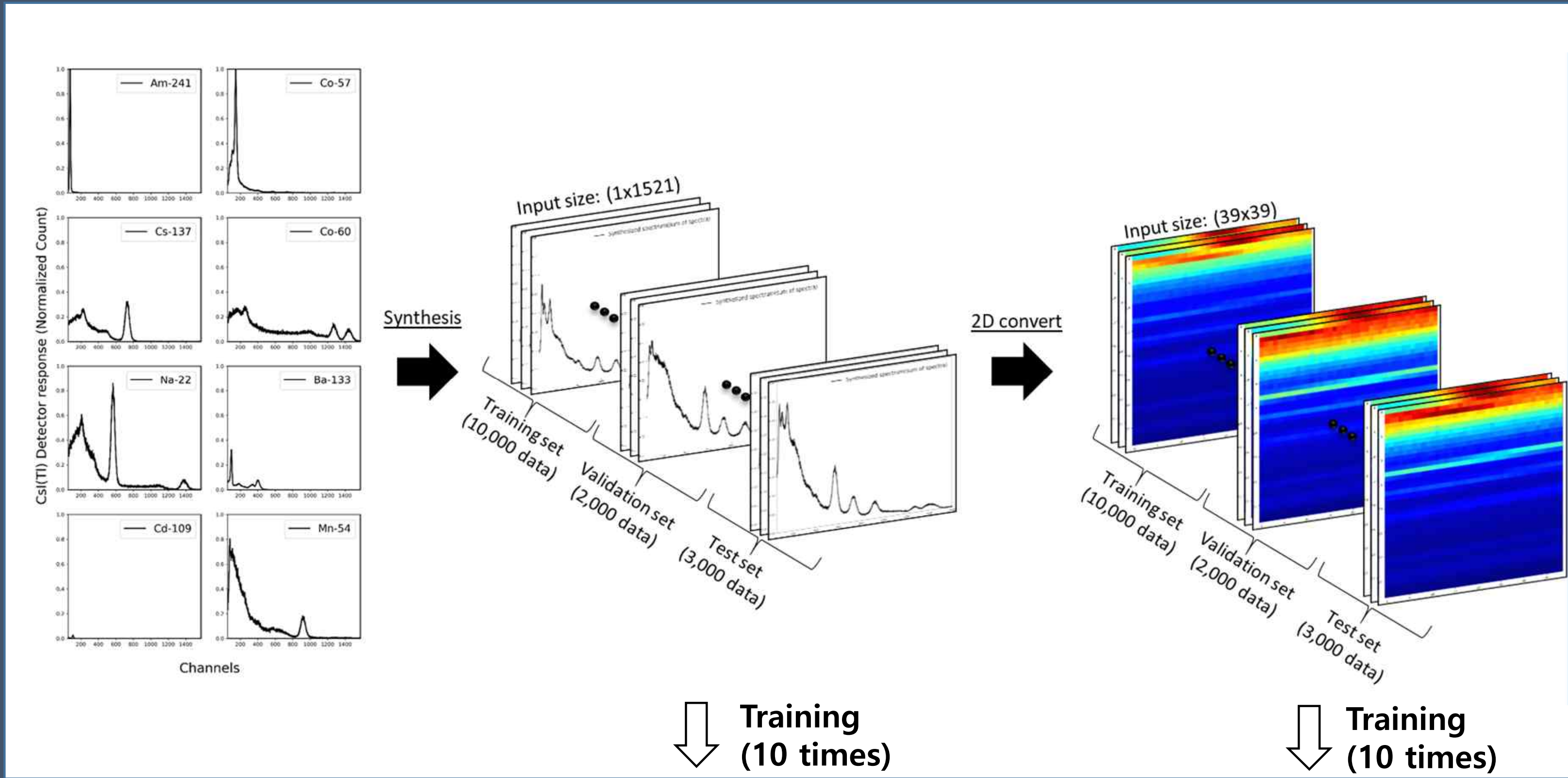
- We sequentially cut 39 channels in the 1D spectral data and arrange them to form 39 rows.



Example of converting (a) One-dimensional synthesized spectral data to (b) Two-dimensional heat map image data

2D transformed data generation

- 15,000 1D spectral data and 15,000 2D data transformed from the 1D data are prepared
- We split each set of the 15,000 data into training, validation, and test sets in the ratio 67:13:20 through random splitting.



CNNs for RIID

- Hyperparameters of both CNNs models are tuned to optimize the performance

Hyperparameters of the CNN models

Parameter	Model trained with 1-D data	Model trained with 2-D data
Input size	height 1, width 1521 (1-D)	height 39, width 39 (2-D)
Filters per convolution layer	32	32
Dense layer nodes	128	128
Filter size	height 1, width 9 (1-D)	height 3, width 3 (2-D)
Pooling type	1-D max pooling (height 1, width 4)	2-D max pooling (height 2, width 2)
Dropout (pooling, dense layer)	0.1	0.1
Activation function (convolution, dense layer)	ReLU	ReLU
Activation function (output layer)	SoftMax	SoftMax
Optimizer	Adam	Adam
Loss function	Cross-entropy	Cross-entropy
Batch size	64	64
Number of classes (output size)	8	8

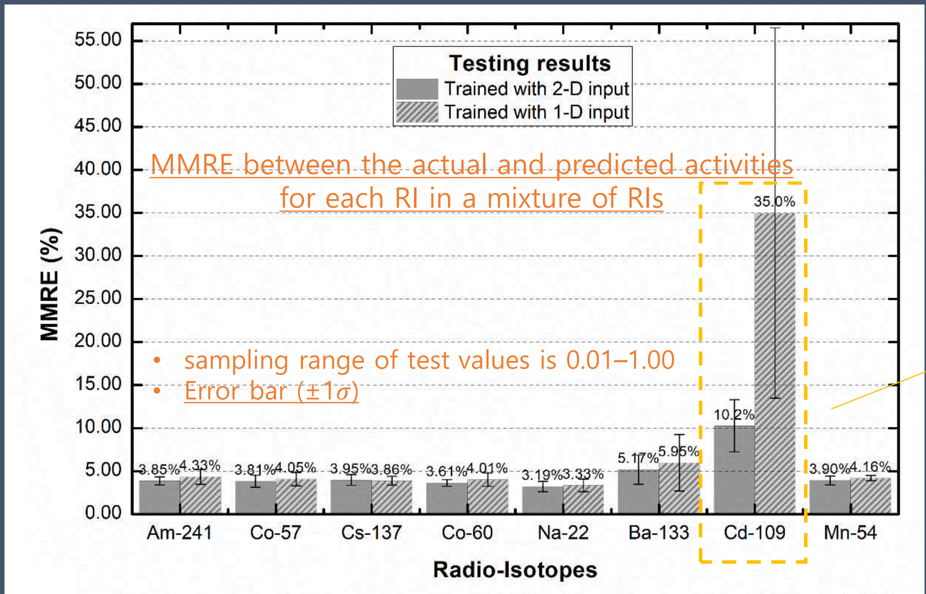
- Evaluation of the performance of the trained CNN models

Mean Magnitude of Relative Error (MMRE):

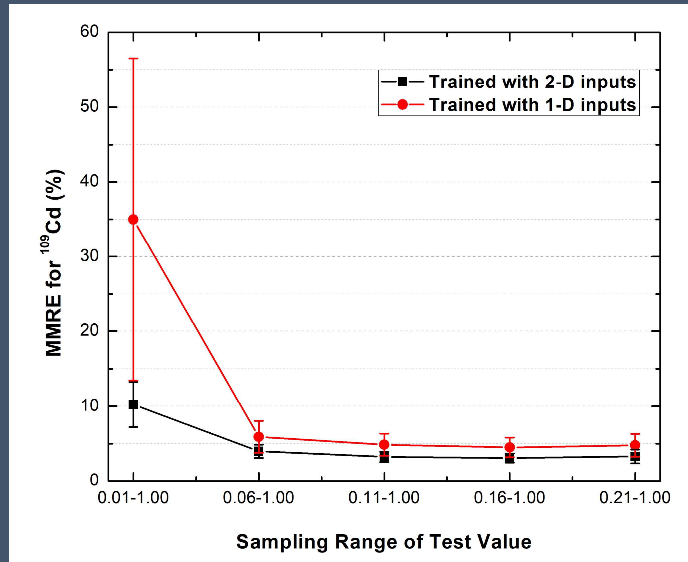
$$MMRE_j(\%) = \frac{1}{n}\sum_{i=l}^{n}\left|\frac{(y_{ji} - \bar{y}_{ji})}{y_{ji}}\right| \times 100(\%)$$

y_{ji} : the test value of the activity for RI j at the ith sampling
$\bar{y}_{ji}$: the predicted values of the activity for RI j at the ith sampling
n : the sampling number for the test set,

RIID performance of CNN models



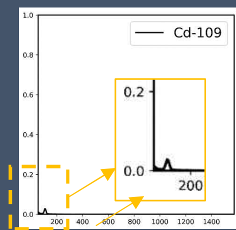
Why ^{109}Cd high?



- The model trained with 2D data exhibits a higher performance except for ^{137}Cs isotope.

(significantly a smaller MMRE and uncertainty for ^{109}Cd)

- MMRE for ^{109}Cd decreases as the sampling range decreases
  -> As relative activity increases, MMRE decreases

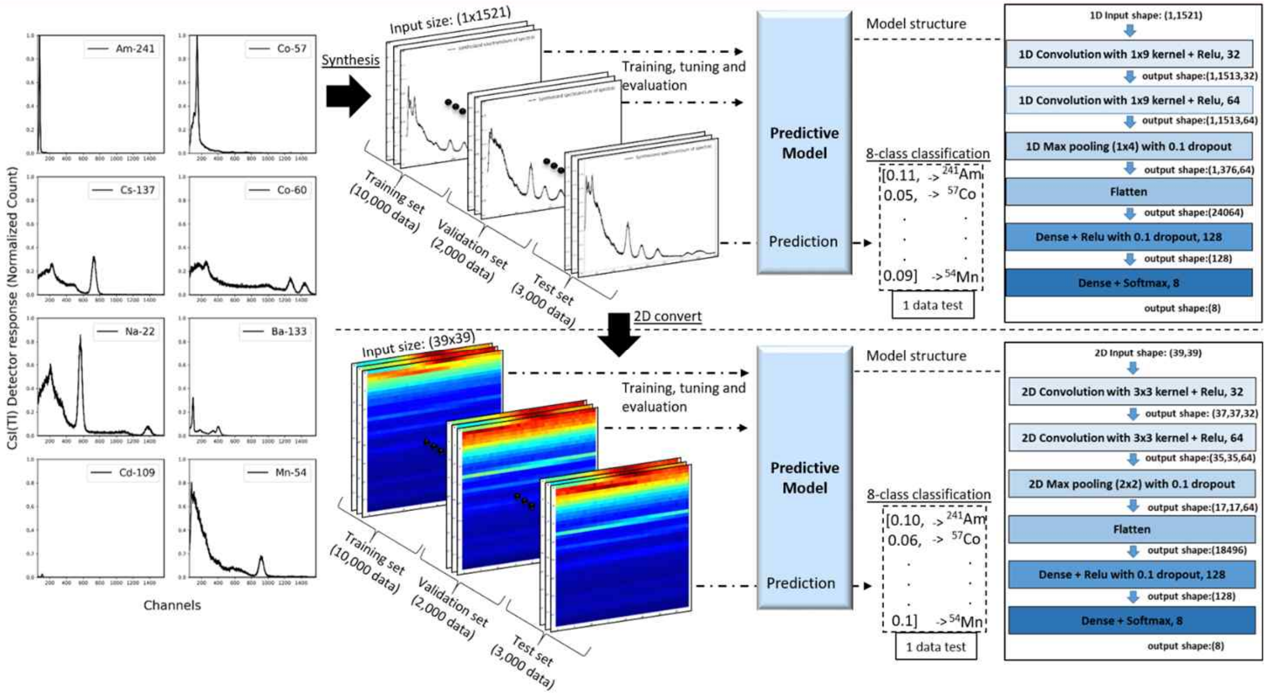


- For both models, the MMRE for ^{109}Cd is significantly larger than other RIs
  -> Because normalized spectrum of ^{109}Cd is smaller than other Ris
- The model trained with 2D data perfoms much better when activity is low

- We use two types of CNNs to identify and quantify RIs in a mixture of RIs through a gamma spectrum measured using a CsI(Tl) spectrometer. (Two types: one is trained by 1D data and the other one is trained by 2D transformed data)

- The model trained with the transformed 2-D data outperforms the model trained with the 1-D data

- Proposed method of transforming 1-D spectra into 2-D data is a promising approach for training CNNs for RIID



Training process based on 1-D spectra and transformed 2-D image data for multi-RIID using CNNs

Thanks for listening

Q & A