Developing Computational Models to Detect Radiation in Urban Environments

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INTRODUCTION

RADIATION

- Radiation is energy traveling in the form of high-speed particles and waves. (Environmental Protection Agency, 2017).
- Radiation can be detected using gamma-ray instruments, such as inorganic scintillators.
- In public areas and events, the presence of a radioactive source (like Uranium-235 or Plutonium-239) can present a risk to the population, and therefore, it is imperative that threats are identified by radiological search and response teams.

SIGNAL PROCESSING

- Signal processing is a subfield of electrical engineering focused on the analysis of data from physical events, which are usually represented in the form of signals (Apolinário & Diniz, 2014).
- The computational model developed for this project uses signal processing methods to detect unnatural (illicit) radiation events in urban environments.

NEURAL NETWORKS

- Artificial neural networks (ANN) are computational networks inspired by the human brain.
- They were first conceived by neurophysiologist Warren McCulloch and mathematician Walter Pitts in 1943.
- Neural networks are used to identify the type of radiation source in energy data, classifying the source as innocuous or harmful, and discerning between weapons-grade material and radioactive isotopes used in medical/industrial settings.

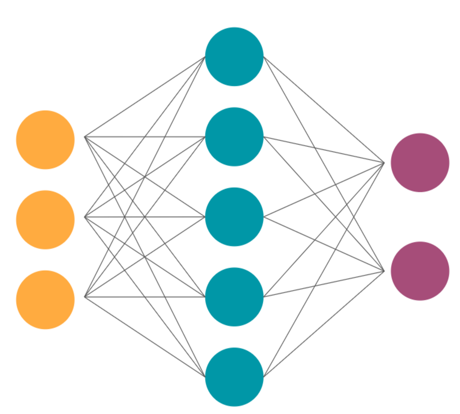


Figure 1. General outline of an artificial neural network. Neural networks can be used to solve regression, classification, and prediction tasks.

OBJECTIVE

- The purpose of this project is to build a **computational model** capable of **detecting and characterizing radiation sources**, using machine learning methods and signal processing techniques.
- The dataset used to build the computational model was generated by the **Oak Ridge National Laboratory** (ORNL) and consists of **25,540 simulations**.
- Each simulation consisted of moving a radiation detector along a street while collecting energy data. Each **street model** had a distinct radiological source, building layout, and building composition (material).

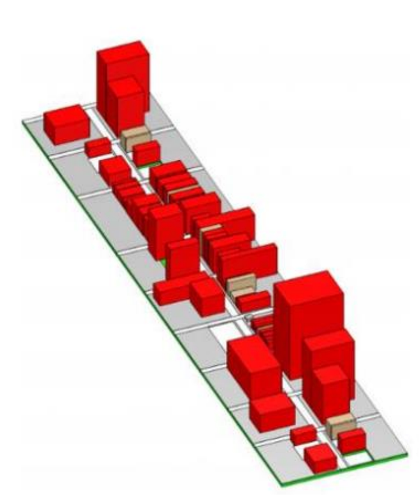


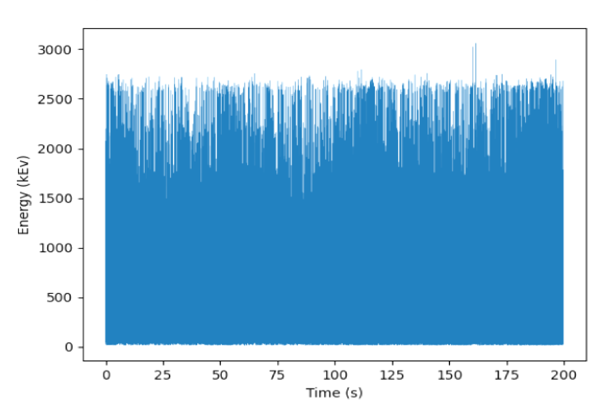
Figure 2: Street-model comprised of brick buildings (red), granite (tan) asphalt (white), and soil (green). The radiation detector collects energy data while moving across the middle street. Source: (Anderson-Cook, et al., 2020)

METHOD

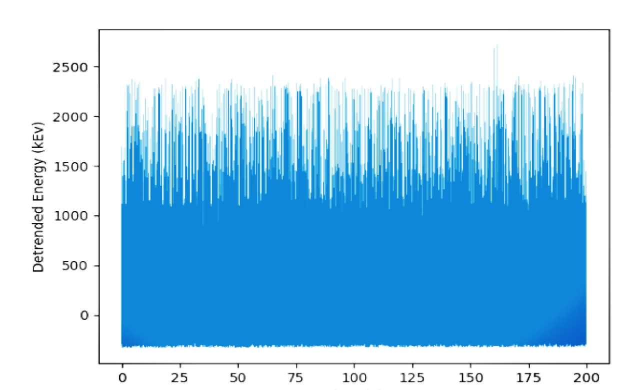
METHOD 1: RADIATION DETECTION

- This project explores the use of signal processing methods to **detect** radioactive sources, following a 4-step process algorithm.

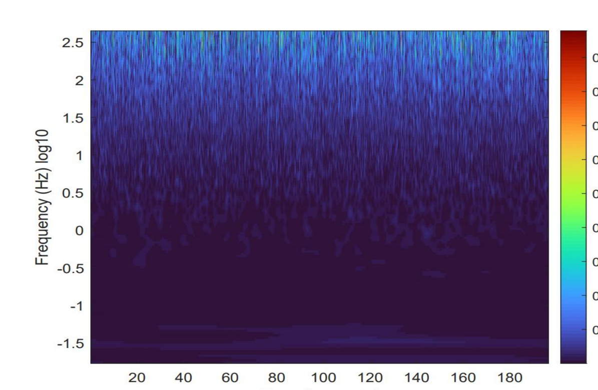
1. ***Pre-processing***: The input data consists of radiation events, described by two parameters: the time elapsed since the last event (previous data instance) occurred, and the energy measured in kilo electro-volts (keV). The pre-processing step **transforms the data** to a 1000 Hz time-vs-energy signal, by averaging the amount of energy detected every 0.001 seconds.
2. ***Detrending***: **Removing the trend** from the data by applying polynomial subtraction. Trends in data are usually the effect of external factors and should be removed before the analysis.
3. ***Filtering***: Butterworth filters are a signal processing method to attenuate frequencies above or below a predefined cutoff. They are used to **remove the noise** from the data, which represents background radiation produced by buildings, cars, and other objects. The data is visualized in wavelet plots, upon being converted to a frequency domain using Fourier transforms.
4. ***Post-processing***: Upon converting the data back to the time domain, the algorithm uses polynomial subtraction to **identify the largest deviations** (peaks and troughs) in the curve, which indicate the presence of a radioactive source.



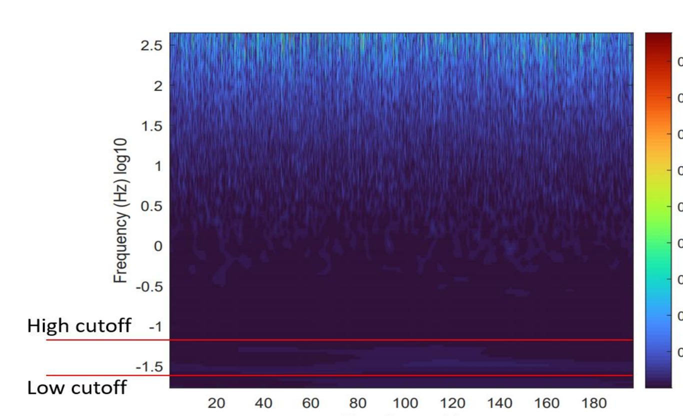
Step 1: Pre-processing.



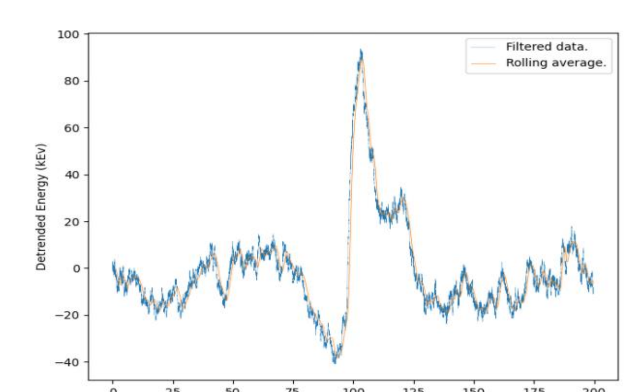
Step 2: Detrending.



Step 3a: Converting to frequency domain (wavelet plot).



Step 3b: Applying a Butterworth filter.

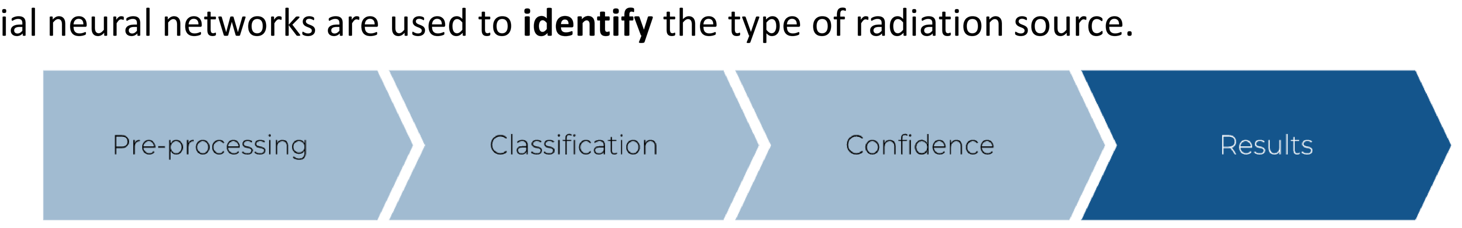


Step 4: Post-processing.

Figure 3. Method 1 process. In this specific simulation, the radiation event occurs at t = 109 seconds, which can be determined by looking at the highest peak in the output of the model.

METHOD 2: RADIOACTIVE SOURCE IDENTIFICATION

- Artificial neural networks are used to **identify** the type of radiation source.



1. *Pre-processing*: Converts the data from a time-energy to an energy-frequency format, to generate **energy spectrum** plots. The energy spectrum plots are created using data for a time window of 2.5 seconds before the radiation event occurs.
2. *Classification*: A 5-layer artificial neural network was used to **identify the type of radioactive source** using the energy spectrum data.
3. *Confidence*: The artificial neural network returns six probabilities, corresponding to each of the radioactive sources. The source with the highest probability is defined as the identified radioactive isotope.

RESULTS

METHOD 1: RADIATION DETECTION – SIGNAL PROCESSING

- The results of the signal processing method show that the algorithm can detect radiation accurately in **77.2% of the simulations**. A detection was defined as accurate when the isotope was detected within 10 seconds of the target time.
- The precision of the algorithm is highly dependent on the type of radioactive source. In general, Uranium Cobalt, and Technetium are easier to detect than Iodine and Plutonium.

Source	Simulations Tested	Detection within 10 seconds of target time (detection events)	Average T_{error} (s) of detection events
Uranium	800	741 (92.6%)	1.27
Plutonium	800	488 (61.0%)	2.62
Iodine	800	429 (53.6%)	2.88
Cobalt	800	728 (91.0%)	1.09
Technetium	800	604 (75.5%)	2.01
HEU + Tech	800	714 (89.3%)	1.42
Total	**4800**	**3704 (77.2%)**	**1.88**

Table 1. Average time error of the model (detection time minus target time) for each radioactive isotope.

METHOD 2: RADIOACTIVE SOURCE IDENTIFICATION

- The neural network model can identify the type of radiation source using energy spectrum data.
- The model was trained using 3,600 training simulations and tested on a subset of 1,200 simulations.
- The neural network was built using Python and TensorFlow and was trained using GPU computing on Google Colaboratory.
- The model was can classify radioactive isotopes with high accuracy. 92.6% of the isotopes in the testing set were classified correctly.

	Uranium	Plutonium	Iodine	Cobalt	Technetium	HEU + Tech	Undetected
Uranium	89.9%	0%	0%	0.5%	0%	6.5%	3.1%
Plutonium	0%	96.3%	0%	0.3%	0%	0%	3.4%
Iodine	0%	0%	98.6%	0.6%	0%	0%	0.7%
Cobalt	0.6%	0.3%	0%	95.8%	0%	0%	3.3%
Technetium	0%	0%	0%	0%	82.1%	5.4%	12.5%
HEU + Tech	3.4%	0%	0%	0%	2.6%	92.7%	1.3%

Table 2. Confusion matrix – Neural network isotope classification using gamma-ray spectrum data

CONCLUSIONS & FURTHER WORK

- The ***signal processing model*** was successful at detecting certain types of radioactive isotopes, such as uranium-235 and cobalt-60. However, the model did not perform well with iodine-131 and plutonium-239. Radiation was detected successfully in 77.2% of the simulations.
- ***Further work*** must be done to understand the physical differences in radioactive isotopes that may lead to a superior performance of the model at detecting certain isotopes over others. The model can also be further enhanced by tuning the parameters of the detrending and filtering algorithms, which include the filter polynomial order, the passband range, and the detrending technique.
- The ***artificial neural network*** can identify radioactive isotopes by examining energy spectrum data with high accuracy. The model properly identified isotopes in 92.6% of the tested simulations.
- ***Further work*** includes testing different types of models, such as convolutional and recurrent neural networks. The performance of the model may also be improved by using more training data or using a data augmentation technique.

REFERENCES

- Anderson-Cook, C., Archer, D., Bandstra, M., Curtis, . . . Quiter, B. (2020). Radiation Detection Data Competition Report. Los Alamos
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