Developing Computational Models to Detect Radiation in Urban Environments

Nicolas Gachancipa

Advisors: Dr. Mihhail Berezovski, Dr. Aaron Luttman

INTRODUCTION

RADIATION

- Radiation is energy traveling in the form of high-speed particles and waves. It is often classified into two classes: non-ionizing and ionizing (Environmental Protection Agency, 2017).
- Ionizing radiation is produced by radioactive materials (which emit gamma rays) and is a product of radioactive decay in their atomic nuclei. High-energy radiation can cause damage to living organisms.
- Radiation is often detected using gamma-ray instruments, such as inorganic scintillators. Radiological sources, such as Uranium-235 and Plutonium-239, are radioactive isotopes which can be used to build nuclear weapons.
- In public areas and events, the presence of a radioactive source 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 ambiances, which may have disastrous consequences if undealt with.

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.

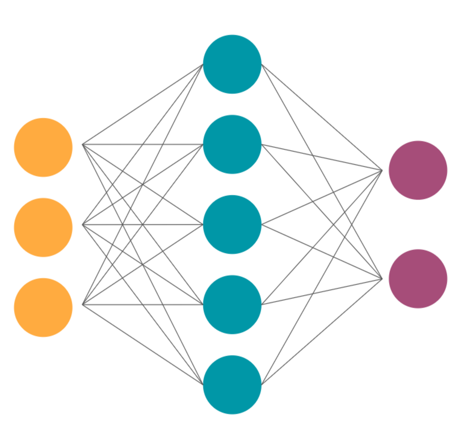


Figure 1. General outline of an artificial neural network. Neural networks can be used to solve regression, classification, and prediction tasks.

OBJECTIVE

The purpose of this project is to build a computational model capable of detecting and characterizing radiation sources, using machine learning methods and statistical analysis. Specifically, the project explores the use of signal processing techniques and artificial neural networks for the analysis of radiation data.

METHOD

DATASET

- The dataset used to build the computational model was generated by the **Oak Ridge National Laboratory** (ORNL) using a stochastic-simulation code (based on Monte-Carlo methods), called MAVRIC (Anderson-Cook, et al., 2020).
- The dataset consists of **25,540 simulations** split between training and testing sets. Each simulation consisted of moving a radiation detector along a street while collecting energy data.
- Each simulation had a **different street model**, each having a distinct radiological source, building layout, and building composition (material). The simulations are being used for training and testing of the computational model.

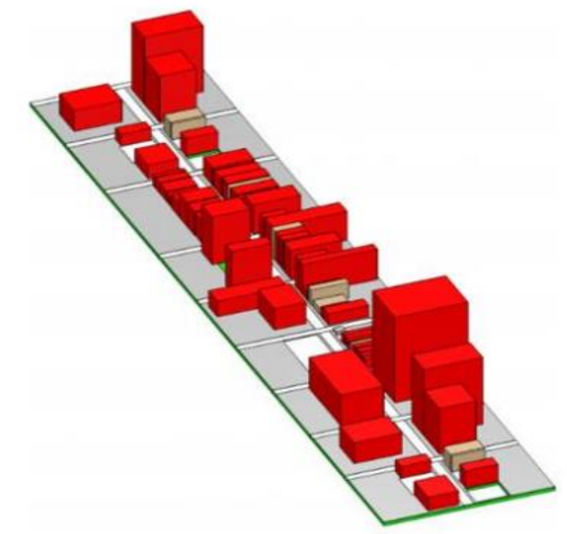


Figure 2: Street-model comprised of brick buildings (red), granite (tan) asphalt (white), and soil (green). The radiation detector collects energy data while moving across the middle street. Source: (Anderson-Cook, et al., 2020)

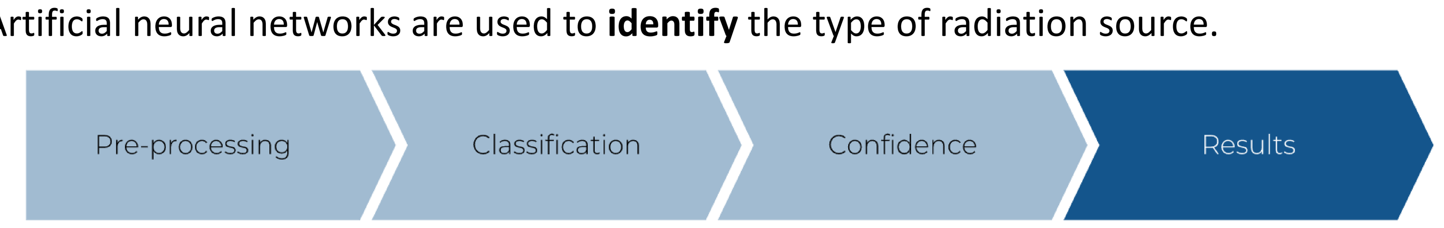
METHOD 1: RADIATION DETECTION

- This project explores the use of signal processing methods to **detect** radioactive sources, following a 5-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. Low-pass and high-pass Butterworth filters are used to **remove the noise** from the radiation data, which is usually representative of 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.

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

- The preliminary results of the signal processing method show that the algorithm can detect radiation accurately in over 75% of the simulations.
- The precision of the algorithm is highly dependent in the type of radioactive source. In general, uranium and cobalt are easier to detect than technetium, iodine and plutonium.
- The following schematic shows the detection process of a Uranium-235 isotope. The time at which the radiation detector is closest to the radioactive source (target time) is t = 109 seconds.

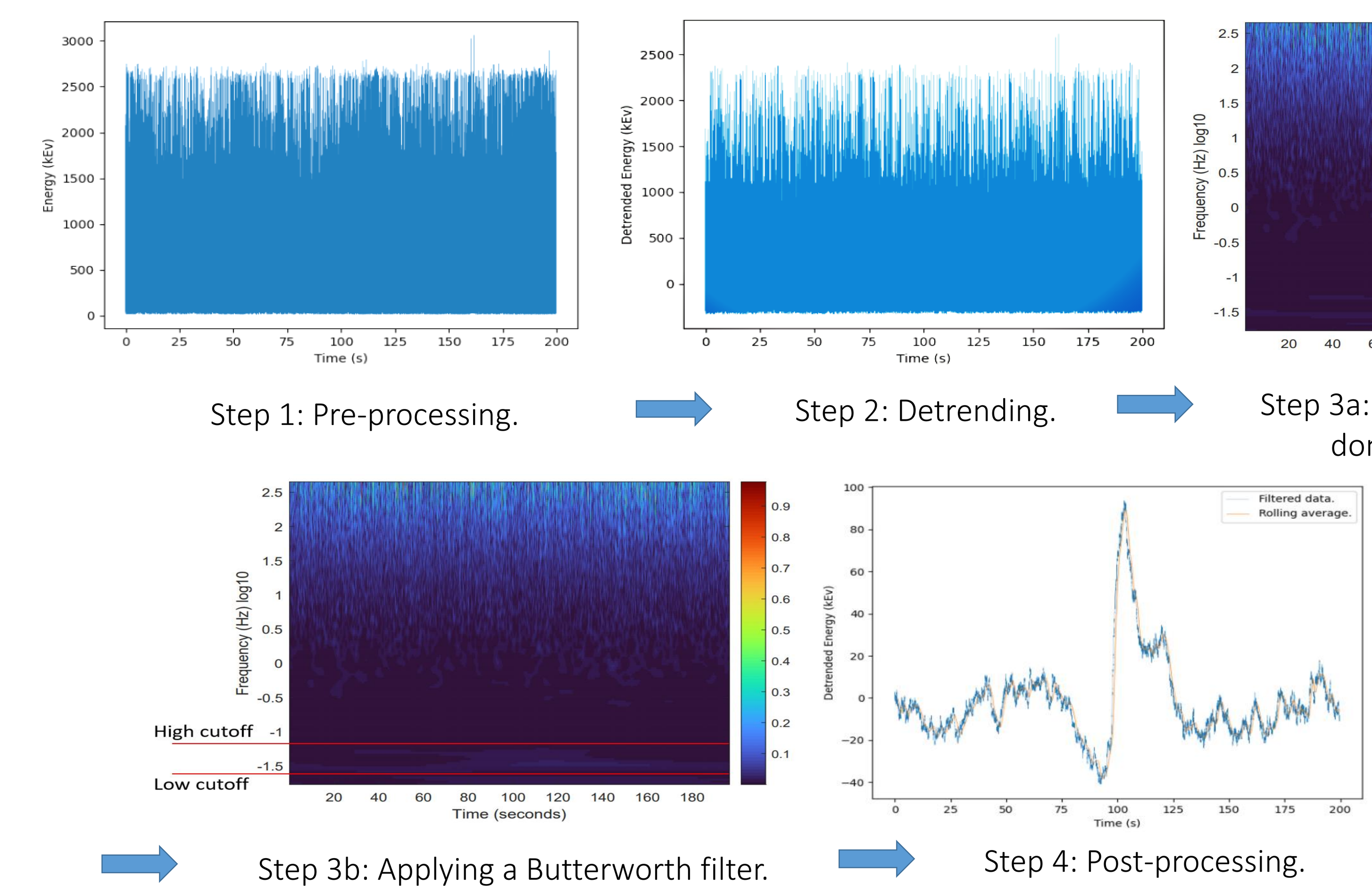


Figure 3. Method 1 process. In this specific simulation, the radiation event occurs at t = 109 seconds, which can be determined by looking at the highest peak in the output of the model.

METHOD 2: RADIOACTIVE SOURCE IDENTIFICATION

- The neural network model can identify the type of radiation source using energy spectrum data.
- The model was trained using 4,400 simulations from the training dataset and tested on a subset of 400 simulations.
- The neural network was built using Python and TensorFlow and was trained using Google Colaboratory.

Source	Accuracy
Highly Enriched Uranium (HEU)	84 %
Weapons grade plutonium (WGPu)	77 %
Iodine (131I)	86 %
Cobalt (60Co)	94 %
Technetium (99mTc)	71 %
Uranium (HEU) + Technetium (99mTc)	80 %

Table 1. Accuracy of the neural network model for different radioactive sources

CONCLUSIONS & FURTHER WORK

- The preliminary results show that the signal processing technique can detect radiation events upon removing the trend and noise from the data. The effectiveness of the method is dependent on the radioactive isotope of interest. Further work includes combining the signal processing algorithm with a convolutional neural network which can infer information from the wavelet plots.
- The artificial neural network can identify radioactive isotopes by examining energy spectrum data with high accuracy. Further work includes testing different types of models, such as convolutional and recurrent neural networks.

REFERENCES

- Anderson-Cook, C., Archer, D., Bandstra, M., Curtis, . . . Quiter, B. (2020). Radiation Detection Data Competition Report. Los Alamos
- Apolinário, I., & Diniz, P. (2014). Signal Processing Theory and Machine Learning. Rio de Janeiro, Brazil
- Environmental Protection Agency. (2017, 03 22). Radiation Exposure. Retrieved from MedlinePlus.