Nuclear Instruments and Methods in Physics Research A 802 (2015) 31–37

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Detecting changes in maps of gamma spectra with Kolmogorov–Smirnov tests

Alex Reinhart [a,*], Valérie Ventura [a], Alex Athey [b]

[a] Department of Statistics, Carnegie Mellon University, Pittsburgh, PA 15213, USA
[b] Applied Research Laboratories, The University of Texas at Austin, Austin, TX 78713, USA

ARTICLE INFO

Article history:
Received 2 June 2015
Received in revised form
19 August 2015
Accepted 2 September 2015
Available online 11 September 2015

Keywords:
Gamma-ray spectroscopy
Radiation monitoring
Anomaly detection
Mapping

ABSTRACT

Various security, regulatory, and consequence management agencies are interested in continuously monitoring wide areas for unexpected changes in radioactivity. Existing detection systems are designed to search for radioactive sources but are not suited to repeat mapping and change detection. Using a set of daily spectral observations collected at the Pickle Research Campus, we improved on the prior Spectral Comparison Ratio Anomaly Mapping (SCRAM) algorithm and developed a new method based on two-sample Kolmogorov–Smirnov tests to detect sudden spectral changes. We also designed simulations and visualizations of statistical power to compare methods and guide deployment scenarios.

1. Introduction

The threat of dirty bombs and lost or stolen radioactive sources has prompted the development of a variety of systems to detect and identify radioactive materials, ranging from van-mounted gamma imaging systems to backpack-based search systems. These systems are typically designed for border checkpoints, source search, or source identification, but not for the continuous monitoring of a wide area. Here we investigate detecting changes in radiation spectra over a wide area, such as a city, stadium, campus, or large public event. Our goal is to develop an automated mobile sensor system which could monitor radiation spectra over time and detect sudden changes that might indicate the introduction of a radioactive source.

The fastest and most sensitive existing method for mapping radiation over a wide area is a low-altitude helicopter survey; the Department of Homeland Security has funded several helicopter surveys of large cities, producing maps used as a baseline for emergency response plans [1,2]. However, the high cost of operating helicopters makes it impractical to use them to monitor a city over a long period of time.

Previous ground-based efforts have focused on source search: traveling through a city and locating a lost or stolen source when no prior radiological survey is available. Because the natural background radiation varies from place to place due to geology and construction materials, these systems must separate natural variation from variation due to a target radioactive source, usually by assuming that natural variation is much smaller than that caused by the target source, or by examining only the energy ranges typical of target sources [3]. This limits their sensitivity—a small target source may hide among the variation in the natural background, or may emit at energies not chosen for targeting.

A long-term radiation surveillance system could avoid this problem by comparing newly recorded spectra with previous observations *at the same location*. For example, we previously developed the SCRAM algorithm, which is meant to be used with mobile detectors that repeatedly patrol the same area, recording spectra with timestamps and GPS locations [4]. The map is divided into grid cells and each cell's spectrum is compared to previous observations in the same cell. SCRAM does not discriminate between source types, instead using its knowledge of the background spectrum to know what spectra are expected.

However, SCRAM has shortcomings: it downsamples energy spectra into only eight bins, which potentially limits sensitivity to small or distant sources, and it requires several repeat mappings of the same area to estimate accurately the covariance structure between energy bins.

We propose a new method based on Kolmogorov–Smirnov tests which, like SCRAM, can detect any spectral changes regardless of type, but requires no covariance estimates and no downsampling, and hence can work with less background data. This method is simpler, has higher power and provides better source localization than SCRAM. To guide detector deployment, we present simulations and visualizations of statistical power which allow operators to find areas of vulnerability.

* Corresponding author.
E-mail address: areinhar@stat.cmu.edu (A. Reinhart).

http://dx.doi.org/10.1016/j.nima.2015.09.002
0168-9002/

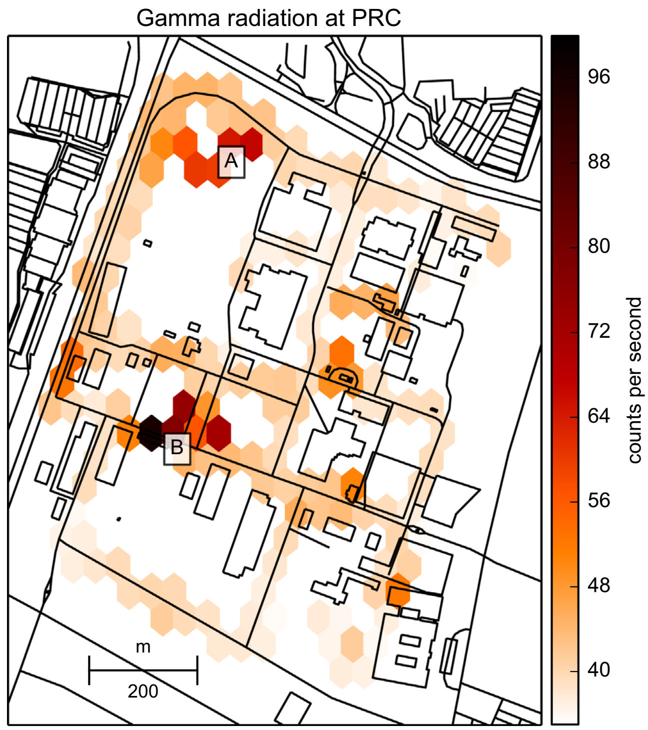

Fig. 1. A map of Pickle Research Campus with total gamma counts per second overlaid; counts are averaged over one month of data collection. Areas of elevated background include the radioactive materials storage facility at the northwest corner (A) and a cluster of large brick buildings near central campus (B). Figure reprinted from [4].

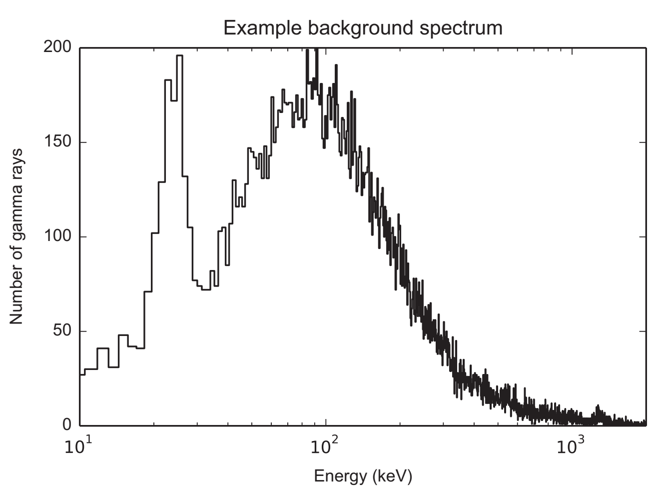

Fig. 2. A typical background radiation spectrum at Pickle Research Campus, comprising 32,173 gamma rays observed over several hours. Energy in kiloelectronvolts, in 4096 bins, is shown on a logarithmic scale.

2. Data

We collected our data using a 2×2 in. Bridgeport Instruments cesium iodide spectrometer, a laptop, and a GPS unit. The spectrometer continuously recorded gamma rays and produced a 4096-bin spectral histogram every two seconds; the laptop then recorded the histogram, time, and location. In typical conditions, 80–120 gamma rays were observed per histogram. An example spectrum, consisting of typical background gamma rays and summed over several hours, is shown in Fig. 2, while Fig. 3 shows a sample taken near a radioactive ^{137}Cs source.

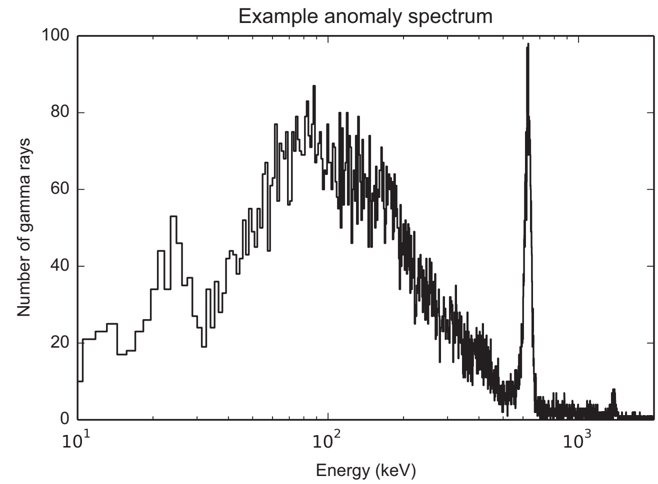

Fig. 3. Spectrum recorded near a sample of radioactive ^{137}Cs. The sharp peak on the right side of the plot, which stands out from the normal background, is the characteristic 662 keV gamma ray emitted in the decay of ^{137}Cs.

The dataset consists of once- or twice-daily drives through Pickle Research Campus (PRC) in the months of July and August 2012. The spectrometer and GPS unit were loaded onto a golf cart and driven around campus for roughly half an hour. Various spectral features at PRC, such as slightly-radioactive brick buildings and a radiological waste storage site, cause the area to have total background radiation levels which vary in space by about a factor of three; this variation is shown in Fig. 1. Cumulatively, the data includes roughly 18 h of observations taken over 41 drives through campus on 30 different days.

In the course of our analysis we discovered that the dataset is contaminated: we used our Kolmogorov–Smirnov anomaly detection algorithm (Section 3.3) to compare each day to the previous day and identified days with unusual spectral differences, the largest of which is likely due to a downpour of 7 cm of rain the previous evening; rain can cause large variation in background spectra [5,6]. In the rest of our analysis we excluded this day. (This was the largest rain event during the dry Texas summer, and the only to cause a noticeable anomaly.) This ensures that our estimates of false positive rates (Section 3.3) do not contain true positives; we shall instead use simulated sources of known size and location to test our algorithms. Future work may be able to account for rain-induced spectral changes using a model to relate precipitation rate and radon progeny deposited by rain [7].

3. Approach

To detect radioactive sources, two things are required. The first is a way to account for the natural spatial variation in background spectra (Section 3.1). The second is an anomaly detection algorithm which compares the background model with new observations and tests for statistically significant differences, producing a map of anomalous regions (Sections 3.2 and 3.3). Global false discovery control is essential to make the system practical, and the power of the procedure needs to be established for target radioactive sources.

The anomaly detection algorithm should use only the shape of the spectrum, not the total count rate, since observed count rates will vary widely depending on the detector, and a wide area monitoring system may use different sizes of detectors mounted on different vehicles at different heights. Also, like SCRAM, our anomaly detection algorithm does not attempt to discriminate between benign and threatening anomalies, instead searching for