J Radioanal Nucl Chem (2017) 314:1095–1101
DOI 10.1007/s10967-017-5479-4

Citizen-based environmental radiation monitoring network

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Received: 27 June 2017 / Published online: 21 September 2017

Abstract This paper discusses a Citizen Radiation Monitoring project designed and implemented by the Natural Resources Defense Council . The goal of the project was to implement a radiation monitoring system that provides radiation data accessible to the public. The monitoring system consisted of usage of a radiation detector integrated with near real-time data collection and visualization. The monitoring systems were installed at five different locations and background radiation measurements were taken. The developed monitoring system demonstrated that citizen-based monitoring system could provide accessible radiation data to the general public and relevant to the area where they live.

Keywords Citizen science · Environmental radiation monitoring · Real-time data communication

Introduction

The Daiichi Nuclear Power Plant accidents in Fukushima have increased the desire of ordinary people to pay attention to radiation monitoring activities. This desire is particularly significant considering that radiation monitoring data in Japan following the accident was inadequate and largely inaccessible to the affected public. Where environmental radiation data is purportedly available, it is usually not relevant to the community of a given area. As a result, various citizen science-based environmental radiation monitoring programs were launched to address these problems [1, 2].

This paper discusses a citizen based radiation monitoring system designed and implemented by the Natural Resources Defense Council (NRDC) in partnership with IMI-International Medcom Inc. (IMI). The paper also presents preliminary results from field deployment of the monitoring systems.

Experimental

The designed citizen radiation monitoring system architecture (Fig. 1) consists of a radiation detector, solar panel with a rechargeable battery, wireless data communication module, and a framework for data management and visualization.

Radiation measurement system

The radiation monitoring project is based on Hawk Radius radiation detector designed and manufactured by IMI. The radiation detector is a Geiger–Mueller (G–M) detector. In this project, G–M detectors were chosen because they are one of the oldest radiation detector types and widely used detectors. Also, they are simple to use, easy to operate and are low cost [3, 4].

The radiation detector has two channels. Channel 1 is a Halogen-quenched pancake G–M tube (LND 73126), and Channel 2 is a Halogen-quenched energy compensated G–M tube (LND 7128). Channel 1 can detect beta, gamma, and x-radiation and can be configured to detect alpha radiation as well if the detector is used for surface

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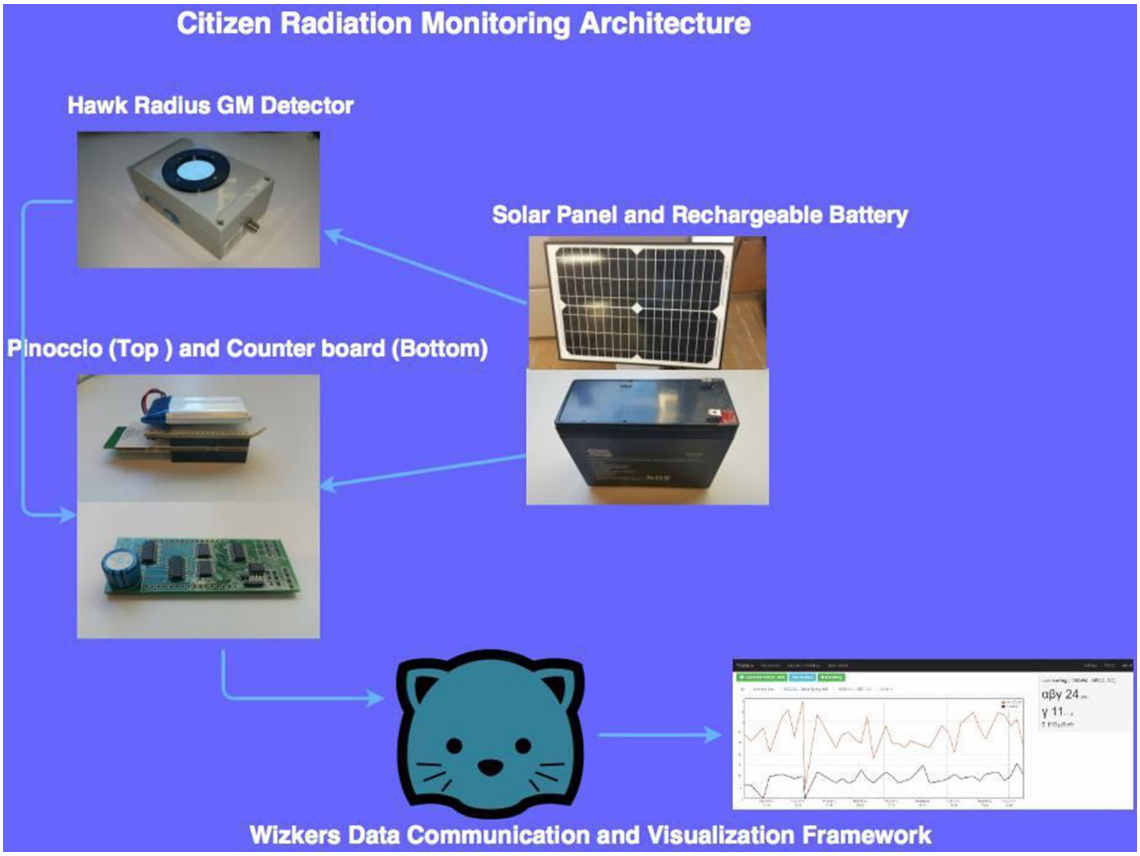


Fig. 1 Citizen radiation monitoring architecture

contamination measurements. The energy compensation design of Channel 2 is to provide radiation dose rate for penetrating gamma radiation. A list of specifications and detailed information on the detector's design can be found in [5].

Data acquisition and transmission systems

Radiation data acquisition, communication, and transmission were based on a wireless microcontroller called Pinoccio [6]. Pinnocio is a complete toolkit (hardware and software) for building wireless, web-enabled projects. It is a wireless microcontroller with Wi-Fi, built-in radio, Mesh Networking, and rechargeable battery. It consists of an ATmega256RFr2 microprocessor, a USB interface, a temperature sensor, an RGB LED, and a LiPo battery. The Pinnocio also has a full-featured REST (Representational State Transfer) API to connect the board to the web. Pinoccios are compatible with the popular Arduino open source hardware platform and make use of its development tools for uploading software to the devices.

The complete Pinoccio based radiation monitoring system can be seen in Fig. 2. In this system, the Pinoccio board is customized to be integrated with the Hawk Radius, a solar panel, and a 12 V rechargeable battery. The Hawk Radius is powered by a solar panel and a 12 V rechargeable battery. A solar power controls the solar power input voltages and outputs a regulated 12 V which will then be converted to a 5 V required by the detector and 3.3 V required by the Pinoccio. As designed, the monitoring stations have enough energy storage, in the form of Lead-Acid Gel cell, to operate continuously for approximately 5–6 days without sunlight. The 12 V battery is charged via a Solar Charge Controller Module. Receiving radiation data and time stamping is done by the counting and processing module. This module provides a custom designed dual counter and Real Time Clock (RTC) circuits with integrated SD Card data storage and a "Proto Backpack" board to supply 5 v to the counter board. The counter board receives the raw sensor counts as pulses from the Hawk Radius Probes and buffers the data to ensure that it is not lost due to transient network connectivity issues.

Firmware was developed in C++ to support the Hawk Radius detectors on the Pinoccio. The developed code allows transmission of raw radiation counts from the detector, performs the necessary math functions, stores data in the SD card, assign a time stamp from the RTC, which is then transmitted via the integrated WiFi

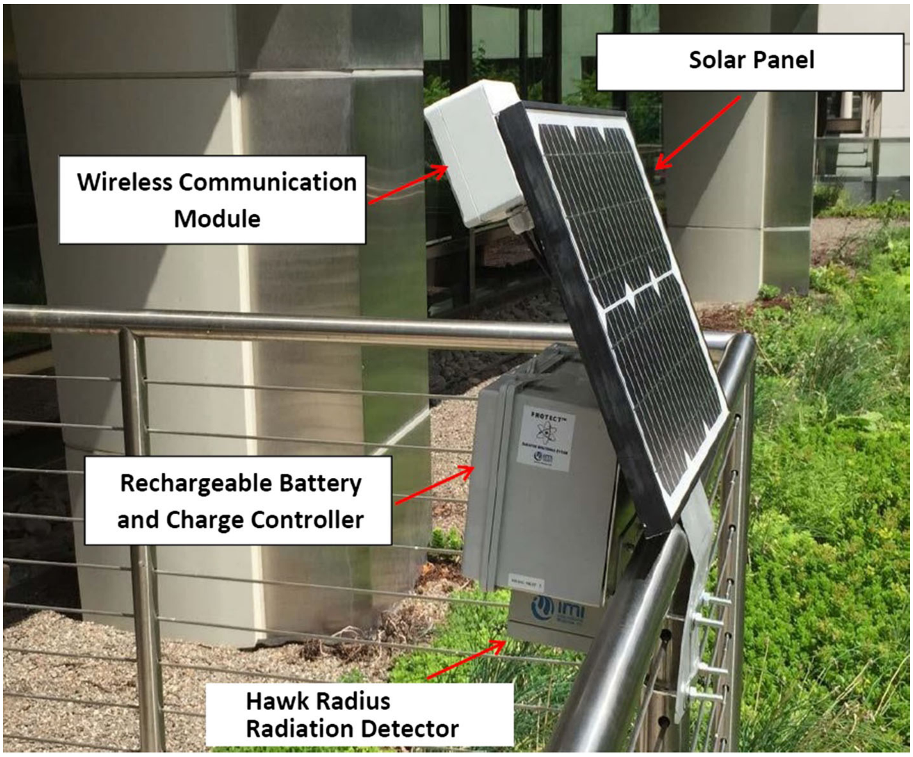


Fig. 2 Pinoccio based radiation monitoring system

Transceiver to an associated WiFi Router and onto the selected server.

When this version was first prototyped, the attempt was to make the station form factor as small as possible. For this, a Lithium-Ion battery and some off-the-shelf hobbyist PC Board solutions for solar charge control, power supply, and maximization of energy capture were chosen. A 6 W solar panel, which would have required a minimum daily period of direct sunlight exposure was also used. The main issues stemming from this were a lack of excess capacity due to battery size, lack of industrial temperature qualification, and complexity and unreliability of the circuits meant to transform low-voltage solar output to the required system voltages. Thus, an established 12 V Solar Charge Controller, long on the market, which was waterproof and meeting the industrial temperature requirements needed for outdoor all-weather use, was used.

It was observed that some development is needed to design an efficient and reliable native charge controller meant for Lithium-Ion cells. In the meantime, Lead-Acid batteries are ubiquitous, easy to replace and recycled at a high rate, but are heavy and bulky. With the move to the 12-volt system, the Charge System board was reduced from 4 separate boards to the one potted module, plus the Proto Backpack board, with both ending up being fully qualified for the standard industrial temperature range. To maximize shorter-window charging opportunities, a larger 18 Watt Solar Panel was chosen. With some additional engineering time, this entire package could be miniaturized, simplified, and optimized for a smaller solar panel and an overall smaller form factor.

Data monitoring framework

A real-time data communication and visualization framework called Wizkers (http://www.wizkers.io/) was used and extended for radiation data monitoring. Wizkers is a universal Open Source application for both data visualization and control of various kinds of scientific instruments. It is a full hybrid Javascript/HTML5 application which runs on computer, Chromebook, phone or tablet. Wizkers can also run as a standalone server application on a Linux platform running on microcontrollers such as Raspberry Pi or Beaglebone Black, or cloud-hosted Amazon Web Services (AWS) instances. Wizkers is an open source cloud system including an open source front-end and backend. Figure 3 shows the Wizkers architecture used for this project.

The philosophy behind the Wizkers project is to address a perceived gap in many Open Source “Internet of Things” offerings, where most projects and frameworks tend to open only the sensors and APIs, leaving the backend, where actual data is stored, closed. Wizkers addresses this gap by providing an open source front-end as well as backend API. Wizkers also makes it possible to rapidly create data collection and visualization infrastructures which can

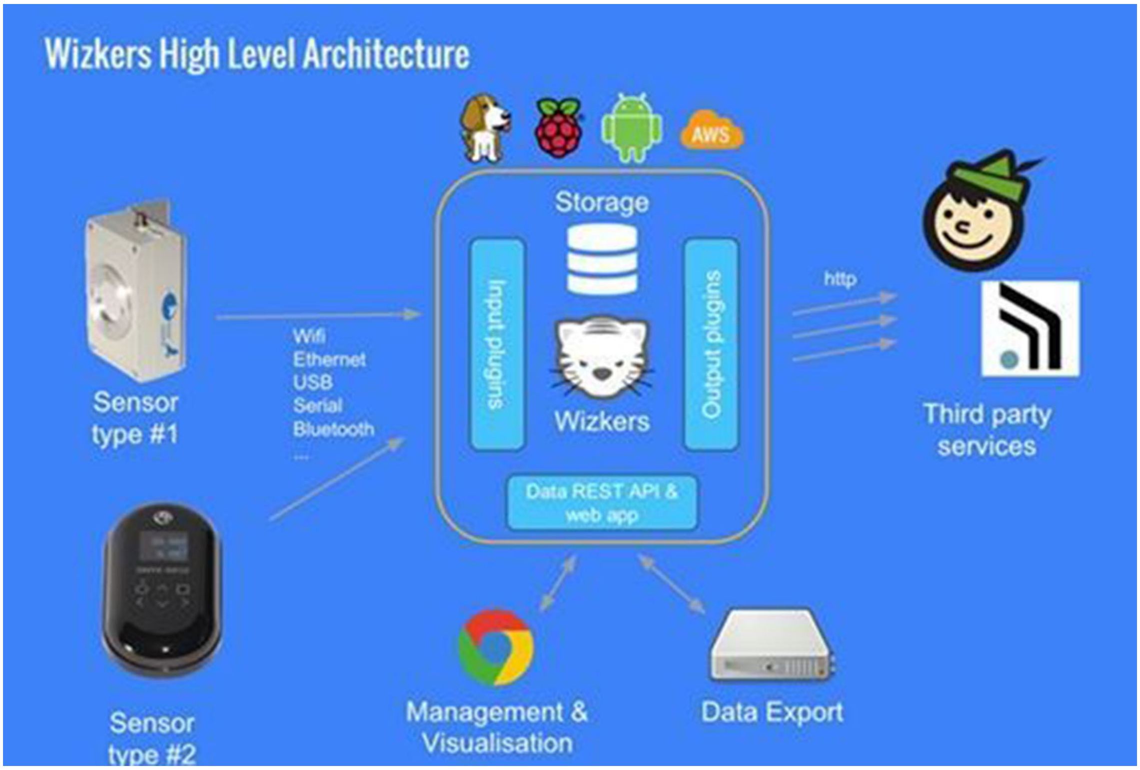


Fig. 3 Wizkers high-level architecture

work independently from an Internet connection if necessary, including local visualization. This functionality is especially important in the context of monitoring networks where there is a need to be able to monitor sensor readings locally even without a network connection, as can be the case in numerous radiation monitoring use cases.

Finally, Wizkers acts as a middleware for the various models of radiation sensors that will be installed. It can also store and visualize data by itself but also forward data to third parties.

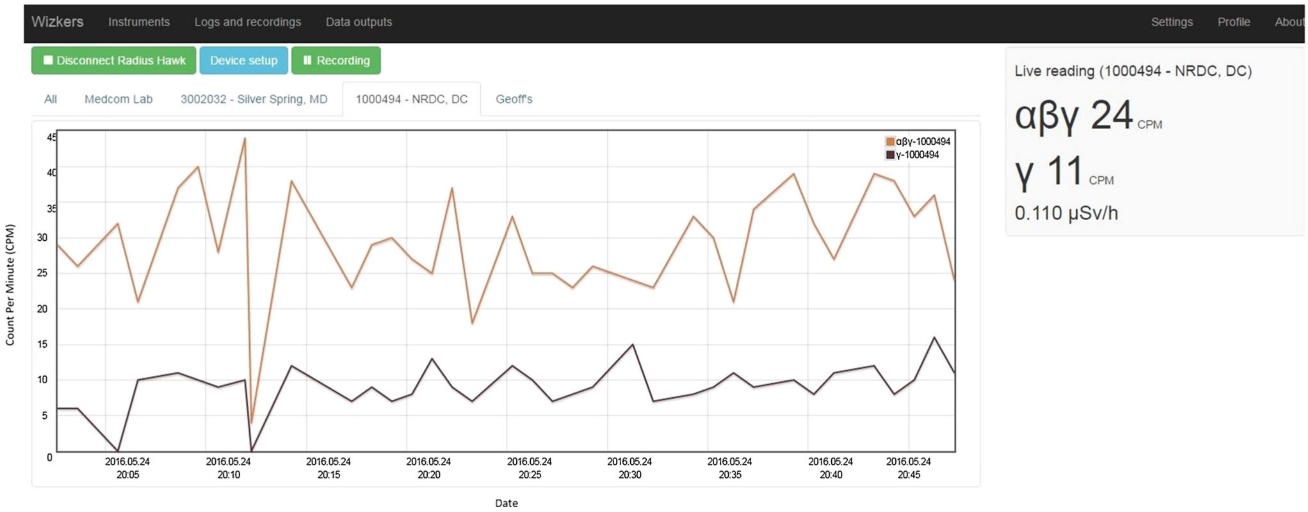
The middleware aspect is especially important to ensure long term support of the detector network. As a concrete example, Pinocc.io decided mid-2015 to change their business model and focus on businesses rather than individuals [7]. This change led to significant disruptions on the Pinocc.io API backend which went down repeatedly for extended periods of time. Since Wizkers was acting as the middleware for all sensors based on Pinoccio, our sensor network was not affected by these disruptions.

The application based on the wizkers framework and developed for this project is hosted on AWS at http://nrdc.wizkers.io/to control, visualize and log data from radiation detectors. Wizkers supports a scalable network for data logging, archiving and data forwarding to other webs services. The main Wizkers user interface dashboard shows all the sensors connected to Wizkers. The "logs and recordings" screen allows the user to visualize the data recordings and download device logs. Default displays on the website include near real-time data in Counts Per Minute (cpm) for each station. Users can also select individual stations to see graphic outputs from both channels of the sensor (Fig. 4).

Installation

To test the network installation, a prototype deployment location was narrowed to Washington, DC, and Maryland. Then volunteers willing to adopt the monitoring station were selected. The Volunteer selection was made by sending out an office-wide email and by presenting our project at the NRDC monthly all-staff meeting. After identifying the volunteers, the next step was to install the monitoring stations at the volunteer's house. Five radiation monitoring stations were installed. Figure 5 shows a map of the installation locations. Figure 6 shows one of the installed radiation monitoring systems.

The Pinoccio technology has enabled sensor data to be uploaded in near real-time for all stations. All the stations are linked by direct or wireless Internet connections.



Live reading (1000494 - NRDC, DC)

αβγ 24 CPM

γ 11 CPM

0.110 μSv/h

Fig. 4 The main screen of NRDC Wizkers. Counts Per Minute (cpm) data from Channel 1 (orange line) and Channel 2 (black line)

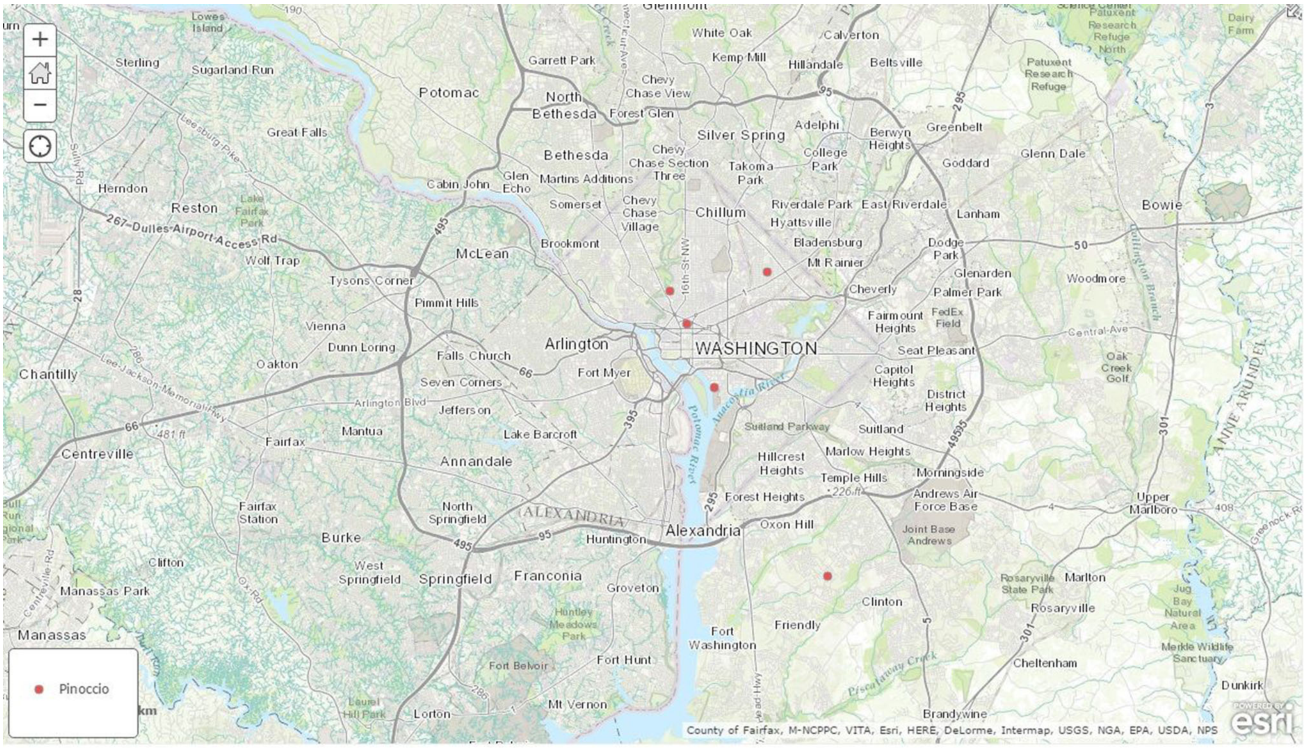


Fig. 5 NRDC Radiation Monitoring Network Map

Results and discussion

Radiation data were collected every minute for six months from October 2015 to March 2016. Data from the readings were then downloaded from the SD card as a CSV file. Data preparation and analysis was then carried out using Pandas (Python Data Analysis Library) Version 0.17.1. Data plotting was done using Matplotlib (Python Plotting Library). The summary statistics for background count measurements are presented in Table 1. The Mean, Standard Deviation, Minimum and Maximum for the background counts are included. As expected, the mean of background radiation ranges between 28.05 and 40.03 cpm for Channel 1 and 8.11–13.33 cpm for Channel 2.

Boxplots of the background cpm for Channel 1 and Channel 2 are given in Figs. 7 and 8. The plots show that there is a variation in background count rate due to changes

Fig. 6 A monitoring system installed in Washington D.C

Table 1 Summary statistics for background count measurements

Station number	Channel	Background counts (counts/min)			
		Mean	SD	Minimum	Maximum
1	1	36.0	0.9	32	42
	2	12.9	0.5	11	15
2	1	38.8	1.5	32	51
	2	12.8	0.5	10	15
3	1	29.9	2.0	11	46
	2	8.1	0.7	4	14
4	1	40.0	4.2	2	51
	2	13.3	1.4	1	16
5	1	28.1	7.4	0	369
	2	9.6	3.5	0	131

in the local radiation levels from background radiation, cosmic rays, radon etc.

A response of the monitoring system for background radiation and radiation release events can be seen in Fig. 9. The figure shows an expected background count rate (Station 2) and an elevated background count rate in the case of a radiation emission events (Station 5). These two monitoring stations are 4 miles apart. The radiation emission event was due to a building x-ray scan that was done one floor below where the monitoring station is installed.

The Hawk radiation detector follow the same principle of gas-filled detectors that radiation passing through them ionize the gas molecules, provided the energy it delivers be higher than the ionization potential of the gas. The charge pairs thus produced can be made to move in opposite directions by the application of an external electric field, resulting in a measurable electrical pulse. A data acquisition electronics then record this pulse as a count [8]. Radiation emission events above the background counts will cause more pulses to be recorded per time which can be seen in Fig. 9 as peaks above the background level.

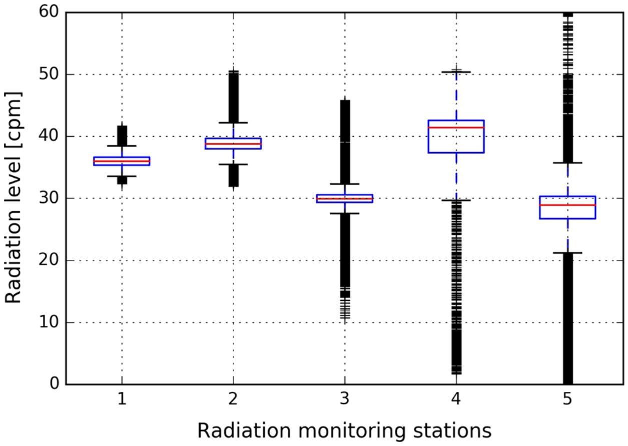


Fig. 7 Boxplot showing the background cpm distribution for Channel 1

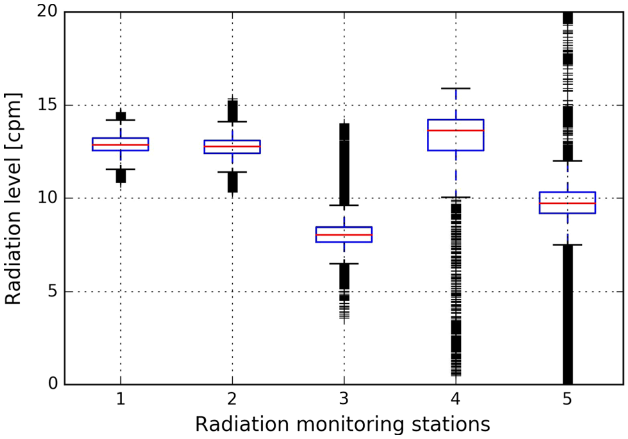


Fig. 8 Boxplot showing the background cpm distribution for Channel 2

The Hawk radiation detector can also provide dose rate for gamma energies. However, in our data analysis for this paper, we have only used the background count rate to show preliminary results of the performance of the detector and the capability of the system of data acquisition and transmission. Once these tasks are checked the monitoring system can be designed to measure and transmit dose rate from the monitoring stations. Dose rate measurement necessitates that the detectors at each station are properly calibrated by exposing the instruments in a radiation field

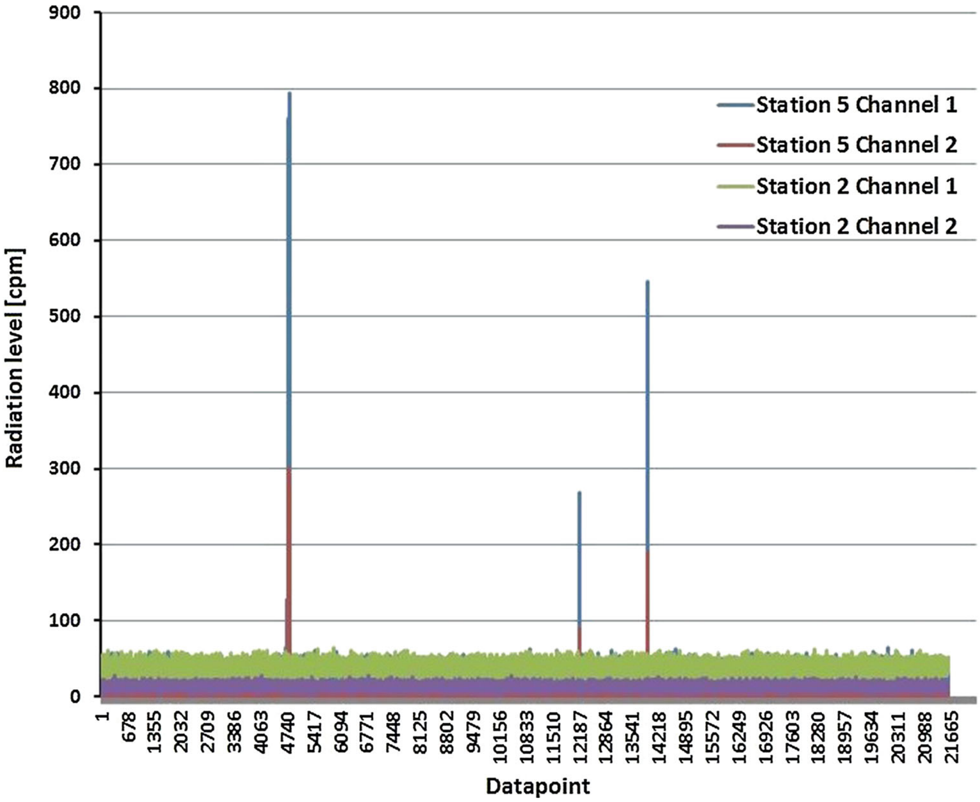


Fig. 9 Background radiation plot for Station 2 and Station 5

of known intensity then conduct a systematic analysis of the radiation level at each station.

Conclusions

The developed radiation monitoring system demonstrated that a citizen-based monitoring system could provide accessible radiation data to the public and relevant to the area where they live. When it comes to large-scale production and expansion of the monitoring systems, an issue that needs to be addressed is calibration of the radiation sensors. Sensor calibration will help to strengthen confidence in the produced data over time.

Wizkers is designed for very distributed and moderately sized networks of sensors. It can nevertheless collect and store very large amounts of sensor data when hosted on cloud infrastructures. It should be noted that its embedded visualization capabilities are currently limited to very large amounts of data. This limitation can be mitigated by the fact Wizkers offers an authenticated REST API to download the data for offline analysis. However, as the size of the network grows; more back-end data processing will need to be implemented to make it possible to scale up efficiently.

Acknowledgements Funding for the Citizen Radiation Monitoring Project was provided by the John D. and Catherine T. MacArthur Foundation.

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