Chapter 1

Smartphone Solutions for Citizen-Centered Risk Monitoring in Environmental Disaster Situations

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ABSTRACT

Through an analysis of three case studies, this chapter proposes a new kind of democratic risk communication that can be realized through environmental sensing by citizens with smartphones, and considers the challenges involved. The three case studies, which the authors have implemented in the society, are as follows: (1) The Pocket Geiger (Pokéga) is a radiation sensor for citizens developed immediately after the Fukushima nuclear accident. More than 100,000 Pokéga units have been produced under an open source license. (2) The Unreal iSOTOPE is a mobile simulator developed for training Japanese law enforcement agencies during radiation disasters. (3) The Pocket PM2.5 Sensor visualizes the distribution of invisible air pollutants indoors and outdoors. It is particularly useful for fieldwork in developing countries where environmental assessments are inadequate.

INTRODUCTION

Global citizens today carry a sophisticated tool for environmental monitoring in their pockets: a smartphone. Smartphones did not exist at the time of the Minamata disaster, the Deepwater Horizon oil spill, the Three Mile Island accident, or the Chernobyl accident, but it is the conviction of the authors that they hold immense potential for public health. In fact, they could play an essential role in minimizing the

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damage caused by such disasters in the future by enabling the public themselves to access live information and determine risk at an early stage through mutual communication with experts.

This chapter discusses three mobile participatory environmental monitoring solutions developed by the authors based on this belief: Pocket Geiger (Pokéga) and Unreal iSOTOPE (USOTOPE) for radiation detection, and the Pocket PM2.5 Sensor for monitoring air pollution caused by PM2.5 (atmospheric particulate matter that has a diameter of less than 2.5 micrometers). Integrating physical and social technologies, these systems use smartphones and social media to empower ordinary citizens to monitor their environment, make sense of the results, and take responsibility for their own health.

The chapter begins with an introduction to Pokéga, a low-cost mobile radiation detector. The discussion concentrates on the socially inflected process by which Pokéga was developed and tested, measurement data was shared, and how effective risk communication was facilitated through social media among citizens, sensor engineers, and radiation experts. With over 100,000 sales to date, it is hoped that the case of Pokéga may provide a helpful model for the social implementation of chemical sensing in the environmental field.

The second solution introduced is USOTOPE, a virtual radiation measurement application for smartphones that uses Bluetooth and Wi-Fi beacons to measure electric field strength and simulate the display of a radiation-measuring instrument. As the discussion shows, USOTOPE provides an innovative solution to the difficulties associated with first-responder training for chemical, biological, radiological, nuclear, and explosive (CBRNE) terrorist attacks. Describing a series of drills carried out using USOTOPE, this section explores other possible uses for the application in disaster drills, including zoning by law enforcement, screening of the sick and injured by medical personnel, and cooperation with the private sector and citizens—all of which have hitherto been difficult to achieve.

The third solution addressed is the Pocket PM2.5 Sensor, a device that can be connected to smartphones to monitor air pollution. As the discussion shows, the device has particular potential in developing countries, where air pollution is responsible for millions of premature deaths annually. This section presents a field study being conducted in Rwanda and explores the potential for gamification to raise the awareness of air pollution in households with children.

BACKGROUND

Environmental disasters that cause severe damage to public health and the natural environment are a constant global threat. In traditional risk assessments, such as those described by the United States Environmental Protection Agency (1992), risk management is determined by expert discussion and top-down decision-making. In contrast, the authors believe that citizen-centered participatory monitoring holds the key to effective disaster prediction, prevention, and response.

Burke et al. (2006) originally presented the concept of participatory sensing and predicted that the data collected from mobile sensors held by citizens could be used for public health, urban planning, natural resource management, and documentary filming. With the spread of smartphones, this concept has become a reality. For example, road congestion, consumption behavior, location information, and travel history are widely collected and utilized through Global Positioning System (GPS) sensors and payment modules pre-built into smartphones. The authors take this concept one step further with the addition to smartphones of environmental sensors for crisis communications.

Malone (2004) proposed that society would move from a centralized management approach based on command and control to a more decentralized model of coordination and development. In the context of disaster management, this would mean respecting and promoting citizen-level disaster information gathering, democratic consensus building, risk-averse behavior, and risk communication. Turoff et al. (2010) highlighted the effectiveness in crisis communication of unofficial, user-generated information (e.g., backchannel information or wisdom of crowds), produced by ordinary people through social media. At the same time, they also indicated the risks of misinformation or overconfidence (or over-diffidence) and the difficulty of sharing information with official bodies. These issues were starkly exposed in the radiation measurements after the Fukushima Daiichi nuclear accident in 2011. The Pokéga section of this chapter shows how trust can be improved by the sharing of government and citizen measurements with each other on social media or by citizens and experts engaging in radiation risk discussions. The International Atomic Energy Agency (IAEA) wrote in a report submitted after the Fukushima Daiichi accident: "For government authorities and agencies, crowdsourcing certainly is the 'genie that will not go back in the bottle.' It is necessary to accept that this technology is here to stay and that empowerment of the public is not necessarily a negative development" (2014, p. 40).

In the near future, big data collected through citizen participation using smartphones will be able to create a new social framework for environmental risk assessment, disaster prevention planning, hazard mapping, and disaster prediction or detection in collaboration with experts, governments, and municipalities. Moreover, participatory monitoring and discussions on social media can improve public understanding of environmental hazards, enabling agile responses to unpredictable environmental hazards and conservation of resources by administrations. To facilitate such a shift, the authors argue that it is necessary to (1) provide citizens affordable and simple methods to monitor the environment, (2) share the measured results among neighbors and experts through social media, and (3) establish a participatory-type mobile system for monitoring the environment that allows objective discussion and verification of scientific information so that appropriate action can be taken to mitigate risk.

MAIN FOCUS OF THE CHAPTER

The three cases presented in this chapter demonstrate that, with appropriate tools, ordinary citizens are able to collect and visualize a large volume of pollution information themselves through environmental sensing. This creates opportunities for community environmental monitoring and voluntary decision-making through sharing and exchange with third parties and experts. If citizens are able to monitor and share environmental risks on a daily basis, mutually evaluate situations with experts and municipalities, and avoid excessive dependency on the government for such management, a disaster-mitigated society based on self-decisions can be realized, as Tanaka and Itoh (2003) and Takayama et al. (2018) predicted. In such a society, members of the public are empowered to respond appropriately (e.g., evacuate) on their own in the event of a disaster, without waiting for instructions to be given. This approach represents a new form of environmental disaster prevention in which the general public, experts, and the government share information to form a consensus through scientific discussion via social media, and using universal technology bases that are affordable and widespread, such as semiconducting sensors and smartphones. The authors hope that the cases introduced in this chapter will provide a model for implementing systems that can contribute to expanding and improving risk communication on environmental disasters.

POCKET GEIGER

Pocket Geiger (http://www.radiation-watch.org), hereafter Pokéga, is a mobile radiation measurement device (Figure 1). The detector is small, lightweight, and inexpensive because it employs a universal photodiode as a gamma-ray sensor, and signals are processed through smartphones. The measurement range is 0.05 µSv/h to 100 µSv/h, which is sufficient for practical use, and radiation levels can be shared and visualized using GPS location information. A total of six models (Type 1 to 6) have been developed to date, with the first Type 1 model having been crowdfunded through Kickstarter. As of 2020, over 100,000 kits have been shipped, and more than one million pieces of data have been recorded and accumulated. In addition, discussions on radiation protection have been actively held on a dedicated social media community page on Facebook.

Figure 1. Exterior view of the Pocket Geiger (Pokéga) Type 4. Pocket Geiger is available in models from Type 1 to Type 6.

Background

Pokéga was developed by the authors in the aftermath of the Fukushima Daiichi nuclear accident in 2011 to address several perceived risk-monitoring needs. After the accident, radiation doses in the region differed greatly depending on local environmental factors (weather, vegetation, and drainage). For this reason, it became necessary to measure dose information at multiple locations and to share this information correctly among local residents. A need among citizens also emerged for a forum for discussion with experts on correct measurement methods and quantitative risks of radiation. The following discussion explores the responses of industry, experts, government, and citizens after the Fukushima accident, focusing on issues of *measurement*, *sharing*, and *discussion*, which are relevant to the need for, and implementation of, participatory monitoring.

Japanese manufacturers had been selling Geiger–Müller tubes and scintillation radiation detectors before the accident, but they were prohibitively expensive for the general public, ranging from 100,000 to 500,000 yen, and difficult to obtain for several months after the accident due to the rapid increase in demand. As a result, inexpensive, predominantly imported, measuring instruments were introduced into the market. However, a National Consumer Affairs Center of Japan (NCAC) investigation of nine such models revealed that none accurately measured radiation doses due to the low absolute values and high variability of the measurements (NCAC, 2011a). The NCAC received many enquiries related to radiation-measuring instruments – 680 cases from March 11 to the end of November 2011 (NCAC, 2011b) – and there were other cases where incorrect product labeling and usage methods were pointed out (NCAC, 2012), which caused social confusion. It was not until nine months after the accident that a domestic company was able to launch an inexpensive measuring instrument for the general public, but this product did not have a function to share the measured values (S.T. Corporation, 2011).

Compared to these disruptions and delays with commercial products, unpaid volunteer groups of researchers and university officials were quick to respond. For example, five days after the accident, Ryo Ichimiya's Radmonitor311 (https://sites.google.com/site/radmonitor311/) and Safecast (https://safecast.org/) were established as portal sites to centralize radiation information online and publish doses using mobile sensors, respectively, and the geographical distribution of doses became available. However, individual citizens remained unable to measure radiation doses and discuss the risks in their living areas.

By contrast, the response of the government was sluggish. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) established a website (https://radioactivity.nsr.go.jp/en/) to consolidate radiation monitoring information only five months after the accident. Three months after that, in November 2011, it began implementing a real-time dose measurement system in Fukushima Prefecture, and a total of 2,700 monitoring posts were installed in February of the following year (MEXT, 2012). In addition, the Japanese government was slow to release the preliminary results of the Emergency and Rapid Radiation Effects Prediction Network System (SPEEDI) in the immediate aftermath of the accident; it was only due to domestic and international criticism that some results were released two weeks later and the full results two months later (Ikeda & Maeda, 2013, pp. 42–43).

In addition, while the foreign media reported the seriousness of the accident, many experts who appeared in domestic media outlets tended to underestimate it, resulting in a very strong distrust among citizens of the government, mass media, and experts (Masamura, 2013). In order to ensure that accurate information about radiation is disseminated and accepted, it is necessary to develop a scientific discussion based on mutual trust. However, mass communication in the aftermath of the Fukushima nuclear accident resulted in citizens losing faith in experts.

Thus, neither the government nor the private sector has been able to effectively provide citizens with the means to measure, share, and discuss radiation doses in risk communication since the Fukushima nuclear accident. It was in this context in May 2011 that the authors began researching and developing Pokéga as a smartphone-connected mobile dosimeter that would enable all citizens to contribute to measuring radiation. The first version, Type 1, was released in August 2011. More than 15,000 devices were distributed in the first six months because they were the first inexpensive dosimeters for individuals after the earthquake. In addition, Pokéga's use of smartphone technology allows measurement results to be shared and discussed on social media to promote radiation protection.

Design Concept

The design of the Pokéga was determined by the need to quickly develop and disseminate a low-cost device. The authors actively sought to utilize general-purpose parts and off-the-shelf products that were readily available to everyone. Furthermore, releasing the blueprints under an open source license allowed the involvement of many engineers and specialists in the development of the system. The following discussion summarizes characteristic features of the Pokéga design.

General-Purpose Semiconductors

In the past, components such as Geiger–Müller tube and scintillation sensors have been used for radiation measurements. These conventional sensors have the advantage of high sensitivity. However, the sensors and peripheral circuits (photomultiplier tubes, high-voltage circuits, etc.) are expensive and complex and require periodic calibration due to age-related deterioration. Although the principle of radiation measurement using photodiodes is well established (Knoll, 2010, pp. 365–414; Iniewski, 2010, 2011; Spieler, 2005; Dearnaley & Northrop, 1966; Kitaguchi et al., 1996), Pokéga is the first application of a photodiode as a radiation-measuring instrument for the general public.

Smartphones

Connecting the sensor to a smartphone has the following three advantages.

- Low cost, compactness, and light weight are achieved by eliminating parts such as user interfaces and power supplies.
- Easy to improve and add functions through software.
- GPS, communication functions, cameras, etc. make it possible to share information and discuss measurement status.

These features are useful not only for environmental measurements but also for various Internet of Things devices, such as credit card reading and online payment device with smartphones.

DIY Semi-Production

For the initial Type 1 model, a do-it-yourself (DIY) kit method was adopted. Buyers received pre-mounted boards that they then had to place in a FRISK mint candy case, which is readily available throughout Japan (Figure 2). In addition, a 10-yen coin was used as a beta particle shield.

By using these familiar general-purpose materials, it was possible to develop the first Pokéga Type 1 personal dosimeter in three months and distribute it at a price of 1,850 yen. Recently, the appeal of these semi-finished products, such as their low cost and high scalability, has been recognized by society as a new and valuable concept, and it is becoming established as a new style of manufacturing. Examples of this trend include the Maker movement (Anderson, 2014), which involves consumers in product development through DIY, and the "IKEA effect" (Norton et al., 2012), in which customer attachment to a product increases through the assembly of semi-finished products.

Figure 2. Assembling the Pokéga Type 1. The user places the Pokéga board in the mint candy case and uses a 10-yen coin as a shield against beta radiation.

Improvement of a Gamma-Particle Detection Circuit

Over three years and six iterations of the Pokéga (Type 1, August 2011; Type 2, February 2012; Type 3, June 2012; Type 4, August 2012; Type 5, November 2012; and Type 6, December 2014), several improvements were introduced. These include the shift from eight low- to a single high-sensitivity photodiode sensor, which reduced the measurement time from 20 to 2 minutes at a standard air dose of 0.05 µSv/h; energy harvesting technology, which allowed the device to draw power from the smartphone itself; and a built-in anti-vibration circuit and comparator to eliminate noise and control input gain.

Software Development

The software can be downloaded from the Apple App Store or Google Play. Figure 3 shows screen captures of the iOS version. In version 1.0 (left), only counts per minute unit of measurement was supported; the current version 1.4 (center) displays the air dose in µSv/h, along with the standard deviation. The graph also shows the moving average of the dose (solid line) and standard deviation. On the map screen (right), dose values can be plotted using the GPS function to share and visualize geographic trends in dose.

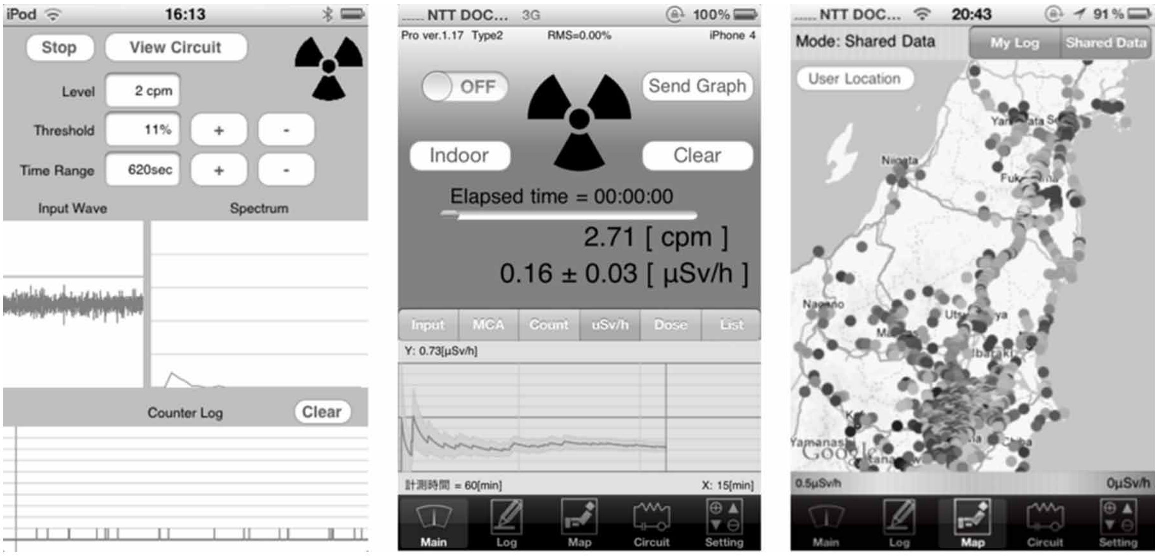
Participatory Development

The development of Pokéga took place with a significant lack of funding and human resources; thus, the authors adopted a participatory development method, as described below.

Crowdfunding

To quickly raise funds for the initial production, the authors relied on Kickstarter, a platform for crowdfunding. The project was successfully funded: the minimum amount needed to produce the initial batch was pledged in four days.

Figure 3. Changes in Pokéga’s software: version 1.0 (left), current version 1.4 (center), map screen of version 1.4 (right)



Media Exposure and Publicity

Although there was no advertising budget, the Kickstarter campaign garnered significant media attention, including features and interviews by various media outlets (e.g., Gizmodo, CNET, Make, Gigazine, Le Monde, etc.). As a result, the project gained significant publicity, which attracted further Kickstarter backers and investment.

Open Source Research

Pokéga’s experimental data, schematics, and software were released under an open source license from the beginning, and can be used for both commercial and noncommercial purposes. This open source development stance, which does not monopolize or secure the results of research and development but opens and returns them to society as common knowledge (commons), is likely to win the support of many engineers, specialists, and researchers.

In fact, the approach attracted offers of cooperation in the development of Pokéga from experts all over the world. The project has benefited from foreign expertise, calibration tests, field tests, circuit simulations, and technical improvement suggestions. For example, a team from the Dutch Ministry of Defence and the National Metrology Office conducted a classification test and issued a certificate of performance free of charge (Kuipers et al., 2011). According to the interview article with the collaborators (Van de Weijer, 2013), strong identification with the purpose of the project was cited as the motivation for these cooperative actions.

A Social Product

A product that has value in terms not only of its function and price but also the user's sympathy for the project's management attitude and social ripple effect is called a social product, which has its own particular value in the market (Auger et al., 2003). Pokéga is such a product. The production and activity base was located in Ishinomaki City, Miyagi Prefecture, which was the affected area. In fact, once the products were released onto the market, the media began to note favorably that they were made in Ishinomaki.

Risk Communication on Social Media

As Pokéga became more popular, sharing and discussion in a dedicated Facebook group became more active. The content of the 1,549 topics posted by users between July 2011 and July 2012 was classified as follows: dose sharing (54%), feature requests (20%), usage (9%), comparison tests (8%), bug reports (5%), and other discussion (4%). A selection of examples is presented next. These examples provide a glimpse into the information that local residents seek in times of disaster and how social media discussions can help to resolve questions.

An example of dose sharing is shown in Figure 4. In these posts, there was much discussion about the sharing of measurements in living areas (city, park, school, home, etc.) and how to understand these values. There were many comments from experts, resulting in a high level of discussion.

Figure 4. Examples of user reports: decontaminated soil has been piled up and a no-go sign erected in a children's park in Chiba Prefecture (left); residents who have been allowed to go home on furlough are holding Pokéga in and around J-Village in Fukushima Prefecture (right)

Through these social experiments, the authors found that the public and experts require different kinds of metadata (e.g., instrument parameters, error ranges, measurement locations, meteorological conditions, etc.) in radiation measurements. Therefore, in 2016, the authors proposed a guideline on metadata for sharing radiation measurements on social media (Segault et al., 2016).

The comparison tests topic relates to accuracy reports conducted voluntarily by users. Comparisons with commercially available air dosimeters were frequently reported. In addition, there were many posts that compared the indicated values at governmental and municipal monitoring posts with Pokéga's measured values. In almost all cases, the measured values were consistent across devices but differently interpreted. Some users concluded that "Pokéga is inexpensive but accurate," while others said that "I thought that the monitoring posts were deliberately showing low dose values so that the government and local governments could control the situation," and "I have come to trust the monitoring posts after seeing the results of the comparison experiment." This positive change in public trust in government and experts is essential if appropriate risk communication in environmental hazards is to be achieved.

In terms of requests and proposals, many suggestions for hardware and software improvements were made on the Facebook group, mainly by engineers. Based on these suggestions, major upgrades were steadily implemented from Type 1 to 6. In addition, non-engineers contributed to the minor version-up of the system for stable operation by generating bug reports for new features. Other questions about how to use the device were also asked, but most of these were resolved through communication among users.

Analyzing the logs of these social media discussions could help predict what kind of information people want after a disaster. Therefore, the authors prototyped Crowd Talks (Ishigaki et al. 2017), a system that visually groups the content of discussions in a Facebook group by combining feature analysis of documents using latent Dirichlet allocation (LDA) and two-dimensional plots using principal component analysis (PCA). It would be useful for disaster response teams and developers of disaster management systems to know the characteristics and changes in the vast amount of social media discussions without having to read them all.

Discussion

During a nuclear disaster, there is a high level of uncertainty about the situation among people, which requires a high degree of cross-disciplinary response and advanced knowledge of radiation protection, even if it is generated by citizen-level action. In order to understand and respond appropriately to complex situations, there is a need for an increased diversity, or spread of viewpoints on the part of people and organizations, which is referred to as collective requisite variety (Weick, 1987). Pokéga could increase the collection and dissemination of more diverse viewpoints of civil society and improve its ability to respond to disasters.

"Citizen science" refers to scientific investigation and research activities by nonspecialist lay people (Silvertown, 2009). In general, data obtained through citizen science have been considered to be prone to errors, making it difficult to ensure adequate data quality (Kremen et al., 2011). However, if citizens share performance-rating instruments such as Pokéga, based on standardized guidelines, the quality of the data can be improved. Furthermore, expertise in measurement methods and the environment can be acquired by citizens through dialogue with experts. With the use of smartphones and social media, the quality of citizen science will break into new territory, and the barriers between citizens and experts may start to blur.

The timing of Pokéga's launch announcement coincided with the birth of the term "crowdsourcing." Crowdsourcing is now widely recognized as a form of online project in which crowds participate not only for monetary compensation but also for the satisfaction of contributing to society and personal growth (Estellés-Arolas & González-Ladrón-de-Guevara, 2012). In recent years, crowdsourcing has become increasingly important, especially in times of disaster, and several projects were launched in the immediate aftermath of the COVID-19 outbreak (some of which can be found on crowdsourcing mentor Codementor's site; https://www.codementor.io/covid19/developers).

Future Directions

Pokéga has been adopted for Berkeley RadWatch (https://radwatch.berkeley.edu) and is expected to be used as a fixed measurement station, taking advantage of its low power consumption. In addition, the authors have been studying the use of Pokéga for the management of radiation exposure of medical personnel in interventional radiology (IVR) since 2017 (Terasaki et al., 2017; Fujibuchi et al., 2019a; Fujibuchi et al., 2019b). In IVR, high levels of exposure to X-rays are a concern because the surgeon performs the procedure, including catheterization, on the patient near the radiology equipment (Chida et al., 2012). Pokéga can be used as an X-ray measuring device in a medical environment, taking advantage of its compact, lightweight, and inexpensive characteristics.

Pokéga will next be used to monitor radiation from natural resources, that is, naturally occurring radioactive materials (NORM) and technologically enhanced NORM (TENORM), which has led to high radiation zones scattered throughout the world. In particular, field research will focus on zircon sand processing and storage facilities in Bangka, Indonesia. Zircon sand, which is widely used in industrial products, generally contains radioisotopes such as uranium and thorium (Hazin et al., 2008). Some facilities in Bangka measured by the authors using Pokéga in 2020 have air-dose rates of 5–20 μSv/h, which is very high for residential areas (Ishigaki et al., 2020) – equivalent to a radiation-controlled area by the standards of developed countries. It is suggested that intervention be considered according to International Commission on Radiological Protection (2007) recommendations.

Of particular concern is that many sandbag clusters are located right next to ordinary homes. Since there are no entry restrictions or guidance signs, local residents, including children, easily enter these facilities. In addition, workers, most of whom come from agricultural and fishing backgrounds, have limited radiation literacy and are not provided with personal dosimeters and masks. Future research steps will include first visualizing the distribution of radiation doses in the region and then examining reasonably achievable goals for radiation protection and education of residents and workers, including medical personnel.

USOTOPE

From a device for citizen-centered radiation measuring, the discussion now turns to a solution developed by the authors to empower first responders in the event of CBRNE terrorist attacks. Drawing on their experience with Pokéga, the authors developed a radiation simulation application for Android smartphones, called Unreal iSOTOPE (USOTOPE), for use in first-responder training, which has been used in drills with field staff from police and fire departments.

Background

Social measures against CBRNE terrorism are attracting attention globally (National Institute for Defense Studies, Japan, 2015). In the event of a nuclear security incident, a radioisotope handling facility disaster, or a nuclear disaster, the scope of impact is vast. The police, firefighters, local governments, and other government agencies are responsible for the first response. This kind of wide-area counterterrorism and disaster response requires special skills, so training is crucial for first responders to gain skills and experience (Tsuchiya et al., 2018a; Tsuchiya et al., 2018b). Particularly in counterterrorism, where radiation and nuclear materials are handled, practical training by law enforcement agencies in activities such as radiation dosimetry, identification of suspicious objects, zoning (hot, warm, and cold zones), and nuclear forensics is vital. From 1993 to 2015, dozens of cases of illicit possession, loss, and perceived criminal activity of radioactive materials occurred every year (IAEA, 2016), which demonstrates the need for more global vigilance and countermeasure training.

However, in training scenarios, it is dangerous for trainees to handle materials that are *actually* highly radioactive. It is also impractical, even for training purposes, to place or detonate highly radioactive materials in public spaces, such as train stations and parks. For this reason, counterterrorism and disaster preparedness training involving radiation and nuclear materials in public spaces often involve taking only fictitious measurements. For example, a training supervisor may announce a pseudo-radiation dose without taking real measurements, despite having a measuring device. In other cases, handmade, nonfunctional measuring devices are used because it is not possible to provide expensive measuring devices to all members of the unit.

Against this background, since April 2016, the authors have developed USOTOPE as a smartphone-based virtual radiation measurement system that shows a screen very similar to professional radiation detectors used by the police or fire departments but with no actual sources of radiation. Instead, Wi-Fi and Bluetooth (BLE) beacons are used to mimic radiation sources, and the virtually obtained radiation levels based on their electric field intensity are calculated and displayed. The distribution of radiation intensity can be embedded on the in-app map in advance so that the defined radiation levels are shown based on GPS location information.

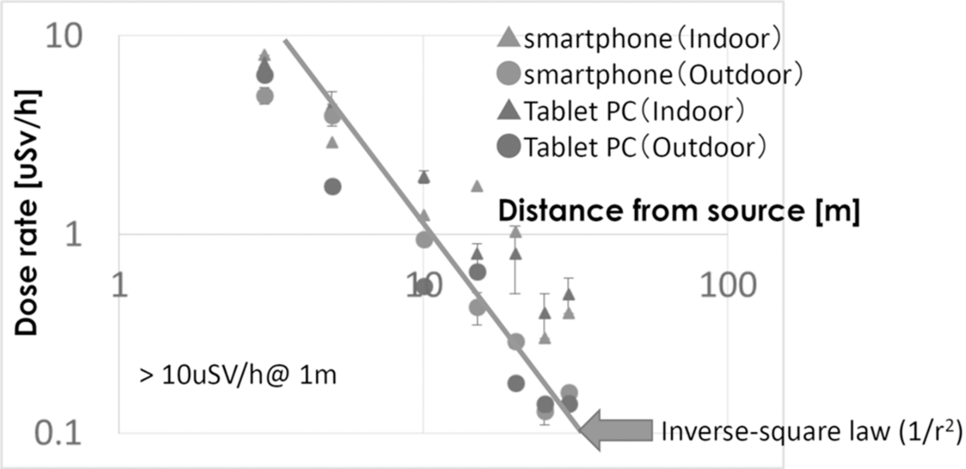
Implementation

USOTOPE is a general-purpose application for Android and can be used on almost all Android devices with wireless communication capabilities. The system uses a dedicated BLE beacon (Aplix JM1L2S) as an imitation gamma radiation source that transmits signals every 100 ms, but Wi-Fi access points can also be used in the second version of USOTOPE developed in 2018. Figure 5 (left) shows the application in use. With software revisions, USOTOPE is able to emulate various measuring instruments in use around the world: Figure 5 (right) shows two types of radiation detectors (scintillation survey meter and ionization chamber) simulated by USOTOPE.

Figure 5. USOTOPE in use: terminal with the application running (left), screen captures of two types of measuring instruments emulated by the application (right)

In general, the intensity of radio waves used for Wi-Fi and BLE communications is attenuated according to the inverse square law ($1/r^2$), similar to that of gamma radiation. The gamma radiation dose emulated by USOTOPE was tested and confirmed to obey a nearly inverse square law (Figure 6). That is, a dynamic range of 0.1 to 10 μSv/h of a simulated gamma radiation dose can be obtained within 20 m from the source location, indicating that radio waves for communication suitably mimic gamma radiation.

Figure 6. Simulated dose rate versus distance from radiation source using USOTOPE on smartphones and tablets



Field Testing

When USOTOPE was first tested in the field in 2016, it was found that users responded so naturally to the application that it was difficult to distinguish it from the actual experience of measuring of radiation. In the test, twelve electronics assemblers with no experience in radiation measurement were given a professional radiation-measuring instrument (Hitachi TCS-172B) and a tablet with USOTOPE installed and set to the task of searching for suspicious objects in three paper bags (one of which concealed both a real gamma radiation source and a Wi-Fi beacon) (Figure 7). The operating principle of USOTOPE was not revealed to the participants until the end of the task, and the order of the instruments used by the participants was changed to reduce sequential bias. The results of a survey on the use of the measurement device, which measured items such as “response and sensitivity” and “ease of measurement” with a seven-point Likert scale, showed no superiority between the real measurement device and the USOTOPE. All the participants believed that USOTOPE could indeed measure radiation. This suggests that USOTOPE is a simple, effective, and realistic tool for education and training.

Through internal testing in the National Research Institute of Police Science in Japan conducted in 2018 (Tsuchiya et al., 2018a; Tsuchiya et al., 2018b), the authors confirmed that USOTOPE is capable of detecting radiological terrorism within a 20-meter radius of a possible threat. After this confirmation, USOTOPE has been used in joint drills between the fire and police departments in Japan since March 2019, as shown in Figure 8, which was taken during a joint exercise involving a railway company at a station in Osaka Prefecture. In this field experiment, the Wi-Fi beacon was also reachable for approximately 20 m. This resulted in the squad members searching for suspicious objects with a sense of reality. In interviews with fire and police crews after the exercise, they rated it favorably because it allowed them to conduct the exercise in a realistic manner.

Figure 7. A participant uses the USOTOPE smartphone app to identify a pseudo-radiation source, but she thinks she is really measuring radiation (left). Participants are looking at a professional scintillation radiometer and the USOTOPE system and answering a questionnaire about the differences between the two (right).

Figure 8. Joint training by police and fire departments using USOTOPE: Radiation source – Wi-Fi beacon hidden in a plastic bag (top left). Surface contamination survey (top right). Team members checking the radiation dose in the air (bottom)

Discussion

Whereas Pokéga contributed to improving risk communication and diversity of thinking in civil society in the post-disaster and recovery process, USOTOPE could be useful in detecting the occurrence of a disaster event itself and quickly identifying its causes. There are three levels of situational awareness: 1) being able to recognize when something happens, 2) being able to identify its cause, and 3) being able to predict the course of events (Endsley, 1995). Level one of situational awareness can be achieved by USOTOPE by detecting high doses of radiation and level two by identifying whether the situation is a nuclear disaster or a nuclear crime and by distinguishing between the types of radiation.

Future Directions

USOTOPE is a unique system that allows people to train for dangerous situations that are difficult to replicate by simulating them on a smartphone. At present, the application can be used for defense training in two of the five possible CBRNE terrorism threats: namely, radiological and nuclear. In the future, USOTOPE could be used for the detection and zoning of chemical, biological, and explosive threats.

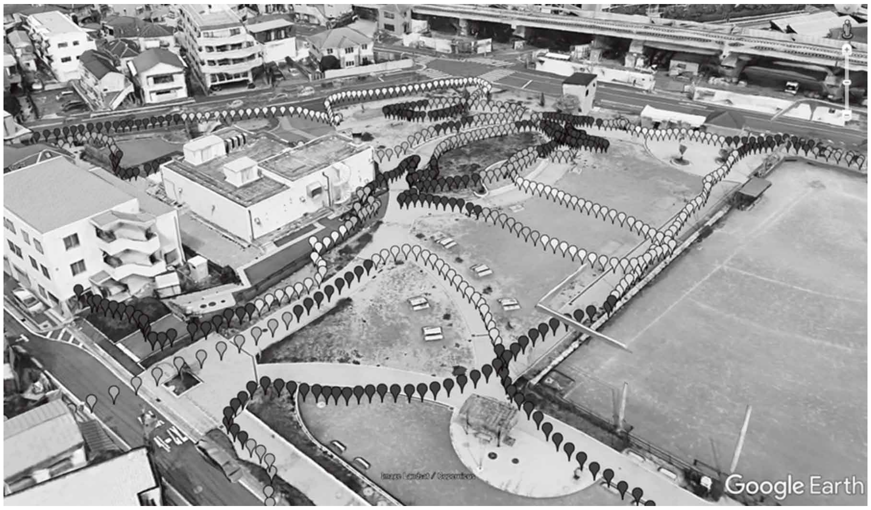
In addition, if the detection range of the measurement can be made shorter and more accurate, it may be applied to radiation medicine, such as for training in the screening of disaster victims for surface contamination and preventing exposure to X-rays in hospitals. Conversely, by increasing the detection range of the measurement to an urban scale, it would be possible to simulate a dirty bomb explosion or train people for a nuclear disaster. Figure 9 demonstrates the next-generation USOTOPE prototyped in 2020. The experiment mimics the display of a predetermined amount of radiation at prespecified GPS coordinates. In an actual explosion and diffusion of radioactive materials, wind direction and the presence or absence of shielding would have significant impact; simulations taking these factors into account can be performed by Monte Carlo simulators such as the Particle and Heavy Ion Transport code System (Japan Atomic Energy Agency, 2020). In the future, USOTOPE will be able to integrate Monte Carlo simulator calculation results with its GPS mapping to simulate radiation doses at a large scale even more realistically.

Now that small radiation sensors like Pokéga are widely used, citizens are also important measurement points. In the case of actual wide-area radiological terrorism, coordination between law enforcement agencies and citizens using consumer radiation detectors should be planned. For example, it would be effective for these agencies to compile citizen-measured data shared over social media to serve as reference information for countermeasures. In fact, the 2016 film *Shin Godzilla* includes a scene of precisely such a response. In the future, USOTOPE could be effectively used for joint training between citizens and the government.

Pocket PM2.5 Sensor

The two case studies presented so far have focused on radiation monitoring. The final case study concerns the Pocket PM2.5 Sensor, a solution developed by the authors for participatory monitoring of air pollution, which, like radiation, is largely invisible.

Figure 9. Prototype of GPS-based USOTOPE: assuming that high levels of radioactive material were placed on the campus, radiation levels were visualized based on GPS location



Background

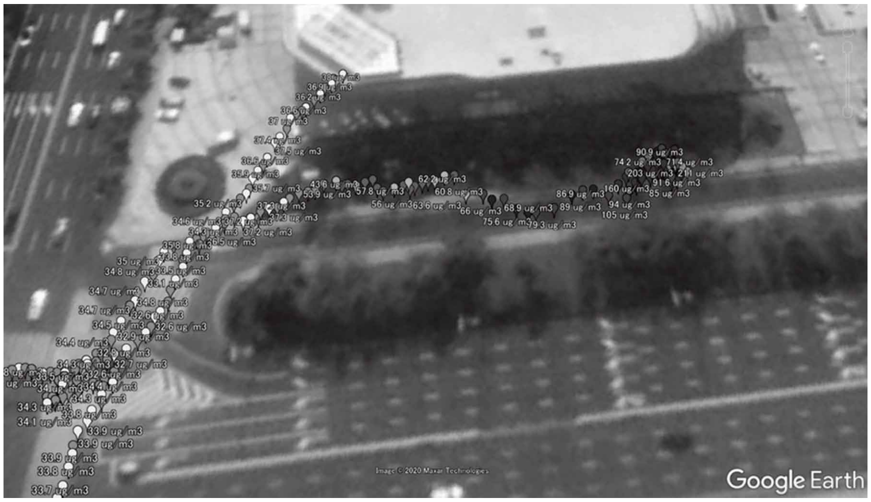
The World Health Organization (2018a, 2018b) announced that seven million people die prematurely each year from lung cancer and respiratory diseases caused by air pollution, such as by microparticulate matter. About 90% of the world's population lives amid polluted air. This pollution is particularly severe in low- and middle-income countries in Asia and Africa, which account for more than 90% of the deaths.

The difficulty for risk communication in these contexts is that PM2.5 (airborne particulate matter with a diameter of 2.5 μm or less) has few acute effects except in certain highly sensitive groups (e.g., the elderly, those with respiratory illnesses, and children). Since most people, except sensitive groups, have no immediate symptoms when they are in a contaminated area, they do not perceive the risks involved. For example, in certain areas in India, the Middle East, and Africa, the authors' field observations show that, even when PM2.5 concentration exceeds 100 $\mu g/m^3$ and cityscapes are conspicuously hazy, people seem to remain unperturbed, and few wear masks because they feel nothing is wrong with their bodies. In the short term, PM-related mortality increases by 2.8% for every 10-$\mu g/m^3$ increase in PM2.5 exposure (Kloog et al., 2013).

It is in this context that the authors, drawing on their experience with Pokéga, developed the Pocket PM2.5 Sensor (Figure 10) in 2016, a smartphone-connected air pollution sensor that enables anyone to measure the concentration of toxic fine particles in the atmosphere. The Pocket PM2.5 Sensor (hereafter Pocket PM) uses a light-scattering method involving a laser light emitting diode (LED) and photodiode to achieve compactness, low cost, and low power consumption. It can measure the concentration of harmful PM2.5 and PM10 (particles 10 μm or less in diameter) in $\mu g/m^3$ within a range of 0–999.9 $\mu g/m^3$. Measurement results, along with GPS location information, can be shared in comma separated value (CSV) or Google Earth KML format and visualized on a map, as Figure 11 shows (Ishigaki & Tanaka, 2017; Ishigaki, Matsuno, & Tanaka, 2017).

Figure 10. Pocket PM2.5 Sensor; the first model was connected to a smartphone with a USB cable, but later improvements enabled Bluetooth connection. The next version of Pocket PM2.5 Sensor [PRO] can store a year's worth of records in its built-in memory without a smartphone, as well as location information via GPS.

Figure 11. Data visualization by Pocket PM2.5 Sensor with Google Earth: the concentration is indicated by blue to red markers. An area of high concentration of 160ug/m³ is visualized on the right side of the screen. There is an exhaust vent from a basement restaurant here.



What is more, Pocket PM changes screen color according to the color-coding rules set by the United States Environmental Protection Agency (2012). This allows even the average user to understand the degree of risk associated with the measurements taken.

Air Pollution in Developing Countries

Pocket PM is now being used in field studies in developing countries such as India, Myanmar, Sri Lanka, Indonesia, Rwanda, Uganda, and China. As this fieldwork has progressed, it has become clear that PM2.5 concentration varies greatly locally—a situation unique to developing countries. In these contexts, financial constraints make it difficult to install many instruments for fixed-point observation of PM2.5. The Berkeley Earth site (http://berkeleyearth.org/air-quality-real-time-map/), which collects data from measurement stations around the world, shows that these stations are concentrated in developed countries. Moreover, when the authors actually measured, it was found that PM2.5 concentration varies greatly depending on micro-environmental factors such as road conditions and use areas. This is possibly related to sources of PM2.5 emissions not found in developed countries, such as uninspected cars and motorcycles, open fires, and roadside industries, seen in authors' field studies in Myanmar and China through 2017 to 2018 (Yi et al., 2018; Ishigaki et al., 2017).

At the same time, there is potential for a significant reduction in personal exposure through individual behavioral change, such as reducing these crude emissions, avoiding living near emission sources, and temporarily taking protective measures, such as using masks and air purifiers. This approach to improving the environment through encouraging individual action is called nudging (Hansen et al., 2016), which holds great potential for advancements in the field of public health. From this perspective, in 2019, the authors began a pilot study of 24-h personal exposure assessment study of PM2.5 using Pocket PM combined with a GPS logger in career women and housewives in Myanmar (Win-Shwe et al., 2019).

Household Air Pollution in Low-Income Countries

Household air pollution (HAP), a form of indoor PM2.5 pollution, is also a serious problem in developing countries. It is particularly prevalent in poor countries in sub-Saharan Africa, the Middle East, and South to Southeast Asia, causing 1.6 million premature deaths per year (Ritchie & Roser, 2014). It is argued that poorer households rely more heavily on primitive solid fuels, such as crop residues, dung, firewood, and charcoal (World Health Organization, 2006). When these fuels are burned indoors, large amounts of PM2.5 are emitted into the room.

Since the figure of 1.6 million is epidemiologically calculated, and it is impossible to know the individual details of those who have died, the real risk of air pollution remains a nebulous concept for most people. PM2.5 has limited acute biological effects such as fainting and convulsions, unlike toxic gas; therefore, even if concentrations increase, its adverse effects are imperceptible in the short term. By contrast, if PM2.5 pollution had a similar acute effect as that of carbon monoxide, for example, ventilation structures of houses would certainly have been designed differently. For this reason, a measurement device that complements human perceptual ability may help to perceive, and therefore mitigate, risk.

Fieldwork in Rwanda

In Rwanda, 98% of rural residents still use open fire stoves (so-called three-stone stoves), with wood and charcoal as the main fuels. In a study by the authors, continuous measurements were taken using Pocket PM in five Rwandan households through 2017 to 2019. The results showed that households using solid fuels such as firewood and charcoal were exposed to high concentrations of PM2.5 in excess of 1 mg/m^3 during cooking, as shown in Figure 12 (Ishigaki, Matsuno, & Tanaka, 2017; Yoda et al., 2019). Those exposed were mainly women – highlighting that this public health issue is also a gender issue – and when the nurse on the research team interviewed participants about their respiratory conditions, they reported subjective symptoms such as coughs and tears.

Figure 12. Use of firewood and high PM2.5 concentration in Rwanda. Most of the housewives in these households have no risk perception about PM2.5.

Figure 13 shows the hourly average PM2.5 for the five households where instruments were installed. Peak concentrations appeared to follow the different households' cooking times, but PM2.5 concentration seemed to vary by fuel type. The use of charcoal was less polluting than firewood, while gas contributed the least pollution.

In order to raise awareness in a local Rwandan community about PM2.5, its risks, and realistic protective measures, the authors conducted a trial workshop with Pocket PM in the village of Twishorezo, outside Kigali, in July 2018. The villagers expressed various opinions, such as "I didn't think there was bad smoke in the kitchen," "Sure, there are coughs and tears," and, "But I have to cook."

The availability heuristic is a form of cognitive bias in which greater visibility and communication about a risk results in greater risk awareness, and, conversely, less visibility and communication leads to increased underestimation of a risk (Folkes, 1988). The Rwandan fieldwork revealed a need among local residents for a combination of increased PM2.5 awareness and inexpensive protective measures.

A demonstration experiment was conducted to install solar-powered ventilation fans in households with the highest levels of pollution in January 2019. Figure 14 shows the moment when ventilation fans were introduced for the first time in a low-income village in Kigali. The ventilator significantly reduced PM2.5 during the hours when the kitchen was used, and adverse symptoms appeared to decrease. Unfortunately, the cost of battery maintenance and the installation of the solar panels themselves proved to be too high for widespread adoption of this system.

Figure 13. Hourly average of PM2.5 concentration in five households in Rwanda. Both No. 1 and No. 2 households use both firewood and charcoal, so they show higher peaks in pollution concentration than the other households. No. 3, which uses gas, has the cleanest air, while No. 4 and No. 5, which use only charcoal, have an intermediate level of pollution.

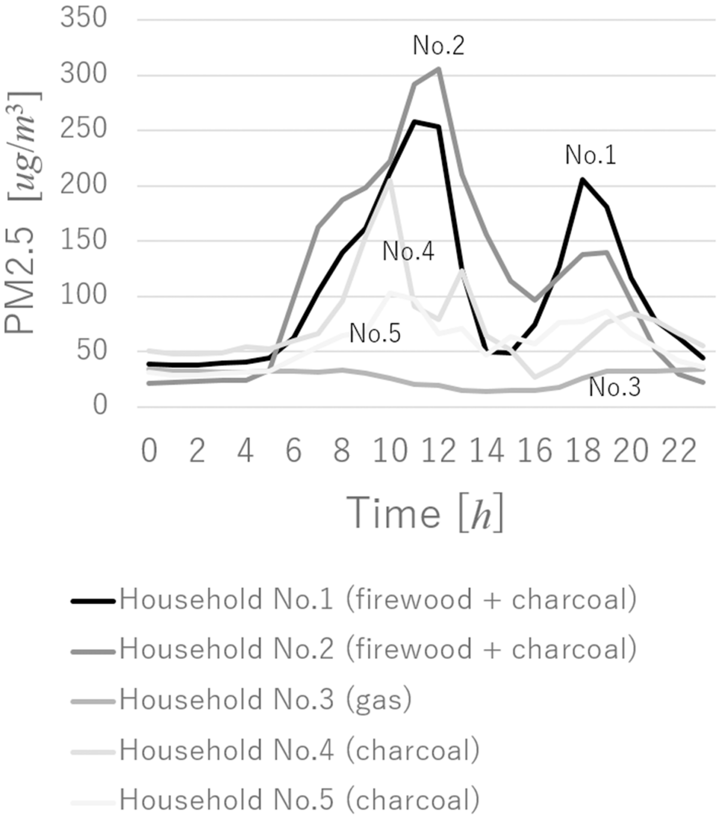


Figure 14. The installation of a solar-powered ventilation system in a house in Kigali, Rwanda. The smoke is discharged from an exhaust vent mounted at the top of the exterior wall. The device is running on solar power and continues to operate at the time of this writing (August 2020).

Discussion

Pocket PM can help residents quantify the current state of the HAP and the effectiveness of measures put in place. Furthermore, continuous data on PM2.5 concentrations collected through the network can be used for epidemiological studies when combined with architecture, aerosol science, or health status.

In addition to technical solutions through improved fuels and equipment, the solution to the problem of HAPs will depend on mechanisms that enable residents to recognize the problem themselves and encourage behavioral change. The process by which individuals gain democratic participation in community life is called empowerment (Zimmerman & Rappaport, 1988). In empowerment for HAP solutions, residents should first have increased awareness and empathy for the problem; second, a sense of self-efficacy that residents themselves can solve problems; and finally, an active participation in effective measures with a sense of ownership. For now, Pocket PM is just a measuring device, but it could be expanded as a tool to achieve empowerment by using smartphones to express information in a variety of ways and by linking with social media, as shown in the case of Pokéga.

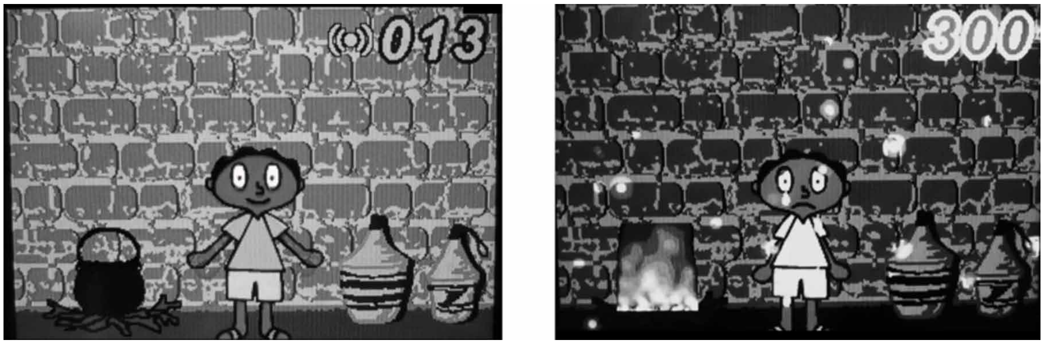
An effective solution to HAP in developing countries has yet to be found. Ideas for solutions could perhaps come from a synthesis of diverse disciplines such as technology, community nursing, and psychology. This approach to problem-solving is often defined as design thinking (Cross, 1982). In the next section, some of the new research ideas currently being prepared will be discussed, combining the entertainment sector with measurement technology.

Future Directions

The next trial in 2020, which will be conducted in Rwanda, is an attempt to enhance risk awareness among local children through gamification, a method that introduces an element of play to learning, in order to achieve objectives efficiently and enjoyably. The trial involves a small gaming device the size of a smartwatch that uses Pocket PM. It will run an interactive-type game that integrates location information, similar to Tamagotchi and Pokémon GO, with a character whose behavior changes according to the concentration of PM2.5 in the air (Figure 15). In this context, children are regarded as important players in health education because their literacy rate and education level are higher than that of their parents' or grandparents' generation (Nyirimanzi, 2012). It is hoped that this game terminal will make them aware of the invisible presence of PM2.5 from a young age and raise awareness within their communities in turn. Because many children in Rwanda attend school, the researchers will work with local schools to advance the demonstration experiment by integrating the game into extracurricular activities.

Globally, there is an activity called Improved Cookstoves (ICS) to promote highly efficient cooking equipment in developing countries (Accenture Development Partnerships, 2012). However, the authors found no one using the ICS in local Rwandan villages. According to residents, the metals and ceramics required for ICS are expensive and cannot be bought by the poor. The number one reason for using firewood is "because it's free" (Butare et al., n.d.). Rural communities in Rwanda require solutions based on "frugal engineering" (Le Bas, 2016) that can be achieved with free materials. A complete solution has yet to be found.

Figure 15. Game design for PM2.5 awareness in children. In the left image, the concentration of PM2.5 is so low (13 ug/m^3*) that the character is living normally, while in the right image, the concentration is so high (300 ug/m*^{3}*) that the character is crying. The color of the background changes from blue to red depending on the PM2.5 concentration.*



DISCUSSION

The ability to accurately measure and visualize environmental disaster situations with smartphones and discuss them freely through social media and citizen journalism seems to enrich social capital in disaster response and thus increases resilience. This section discusses the challenges therein.

Social capital comprises three elements: trust, potential for cooperation, and networks (Paldam, 2000). In Japanese, the term “kizuna” is used to collectively refer to these three states. A year and a half after the Fukushima nuclear power plant accident, the researchers examined changes in Japanese people’s ties and found that people in areas far from the disaster area (e.g., Tokyo and Kyoto) tended to believe that their ties had been strengthened, while people in the affected areas tended to believe that their ties had been weakened. This is due to discrimination against, and rumors about, the affected areas. Therefore, designers of disaster communication systems must give due consideration to fake news and the discrimination the system may bring against infected areas and individuals. In the following section, some specific solutions are considered.

First, appointing a good facilitator helps maintain the neutrality and objectivity of discussions over social media. The authors found that organizing discussions visually through Goal Structuring Notation (GSN) makes it easier for the public to notice scientifically inaccurate opinions and increases the satisfaction and understanding of participants (Matsuno et al., 2016). The visualization of issues and problems through infographics will also aid a smooth discussion. Fortunately, as a result of several individuals, including the authors, acting as volunteer facilitators in the Pokéga’s Facebook group, there is no evidence of unscientific or discriminatory discourse. This is partly due to the fact that Facebook is a real, name-based media. If anonymous media were to be used for disaster communications, it would be worthwhile to consider a rating system for the sender, a system of professional checks, and a reporting system.

Privacy and data reliability are also issues. Mapping measurements of radiation and air pollution can lead to estimates of an individual’s residence and movement history. Spatial interpolation of the set of measurement points would be one solution. Consideration should also be given to the security of deliberately low or high values recorded as a form of sabotage to the system. Data of questionable spatial statistical reliability should be cross-checked and verified by experts.

CONCLUSION

This chapter provided practical examples of the use of smartphones to measure, share data on, and discuss environmental hazards such as radiation and air pollution in order to manage them. In recent years, new types of environmental accident and disaster risks such as radiation, CBRNE terrorism, and PM2.5 have risen in prominence. These risks share three common issues: (1) special equipment is required for risk assessment, (2) the degree of risk differs greatly depending on the location of only a few meters, and (3) a high level of expertise is required for risk assessment.

Pokéga presents a case of citizen-led radiation monitoring in which a large amount of environmental monitoring information has been collected and visualized by making citizens the main body for measurement; the project has supported not only local environmental monitoring but also independent decision-making through sharing and discussion with experts. Whereas Pokéga measures real radiation, USOTOPE works as a handy simulator. Therefore, USOTOPE will be an effective tool in training and educating not only law enforcement personnel but also citizens during radiation disasters or terrorist incidents. In the emergency management of radiation protection, information sharing should be interactive, not only at the public level of the state and administration but also at the civil level. In particular, when considering social issues such as NORM that involve complex regional risk awareness, legal regulations, and economic promotion, data sharing and social consensus building based on scientific discussions are essential. PM2.5 pollution has similar aspects to radiation in terms of protection: humans cannot perceive it, and the general public is largely ignorant about it. The widespread use of smartphones throughout the world, including in the developing world, could give humanity a new organ of risk perception.

In traditional risk assessment, top-down discussions between the risk assessor and manager determine risk management policy. In these scenarios, data measurement, verification, and monitoring are done as needed, but they are largely optional, for expert decision-making is explicitly regarded as the most important. By contrast, the authors believe that big data collected via citizen participation using smartphones may initiate a new relationship of cooperation between members of the public and experts, government agencies, and local governments that will lead to more efficient, dynamic, and robust disaster prevention planning, hazard mapping, and the detection and prediction of disasters. In this new social framework for environmental risk assessment, citizens will be able to build consensus while maintaining trust in government and experts through open access to and visibility of data from public and professional bodies.

If each individual can measure and share environmental risks on a daily basis, avoid unilateral and excessive expectations of the government, and make decisions through mutual discussions with experts and local governments, the realization of a highly literate and self-determined disaster mitigation society becomes possible, in which citizens themselves are empowered to take appropriate risk-prevention actions in the event of a disaster without waiting for instructions. The key to this new society must be the development of new physical, cyber, and socially connected smart sensing services based on low-cost and widely used general-purpose technology platforms, such as semiconductor sensors and smartphones.

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If you are interested in this research, please contact the authors and their research group. We look forward to your participation.

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KEY TERMS AND DEFINITIONS

Crowdfunding: A method of fundraising via online platforms that allows details of any project to be published on the web and investment to be collected from individuals who are interested in investing in it. If put to good use, it can yield not only funding but also good public relations and networks.

Nudging: A method that encourages people to voluntarily choose the desired action rather than forcing them. For example, providing incentives, gamifying and entertaining, and engaging the unconscious through affordance in the design of products, architecture, graphics, and information.

Open Source Research: Research conducted in collaboration with researchers and engineers from around the world through the publication of research results and resources under an open source license. It has been adopted by many in the software sector, but there are some examples in the hardware and healthcare sectors.

Participatory Development: A method of rapidly developing products, goods, and services to meet social needs by involving a range of people (e.g., users, engineers, and researchers) right from the development stage, rather than confining development within a single domain organization, such as a manufacturer or service provider that provides value to consumers in a single direction. Examples include crowdfunding, open source research, DIY use, and social media use.

Participatory Monitoring: A situation where the public takes the initiative in sensing, voluntarily sharing measurement data, and engaging in discussions on social media. It is expected to speed up environmental risk-awareness, improve risk literacy, and create voluntary risk-avoidance behaviors.

PM2.5: Airborne particulate matter having a diameter of 2.5 μm or less. Because it is so small, it can pass through the cells of the embryo and enter the circulatory system, causing death from respiratory and cardiopulmonary diseases.

Social Product: A product that is valued because of the social context in which it was made and its ethical significance. In addition to the traditional values of brand, price, and function, it is considered a fourth value in consumer purchasing behavior.