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CURRENT STATUS OF KURAMA-II*

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Abstract

KURAMA-II, a successor of a carborne gamma-ray survey system named KURAMA (Kyoto University RAdiation MApping system), has become one of the major systems for the activities related to the nuclear accident at TEPCO Fukushima Daiichi Nuclear Power Plant in 2011. The development of KURAMA-II is still on the way to extend its application areas beyond specialists. One of such activities is the development of cloud services for serving an easy management environment for data management and interactions with existing radiation monitoring schemes. Another trial is to port the system to a single-board computer for serving KURAMA-II as a tool for the prompt establishment of radiation monitoring in a nuclear accident. In this paper, the current status of KURAMA-II on its developments and applications is introduced.

INTRODUCTION

The magnitude-9 earthquake in eastern Japan and the following massive tsunami caused a serious nuclear disaster for the Fukushima Daiichi nuclear power plant. Serious contamination by radioactive isotopes was caused in Fukushima and surrounding prefectures, but the existing radiation-monitoring schemes were incompetent for this situation due to damage and chaos caused by the earthquake.

KURAMA [1] was developed to overcome difficulties in radiation surveys and to establish air dose-rate maps during and after the incident. The design of KURAMA was intended to enable a large number of in-vehicle apparatuses to be prepared within a short period of time by using consumer products. The in-vehicle part of KURAMA consists of a conventional radiation survey meter, a laptop PC, a USB-type GPS dongle, and a 3G pocket wifi router. The data-sharing scheme based on a cloud-technology has enabled high flexibility and scalability in the configuration of data-processing hubs or monitoring cars. KURAMA succeeded in the simultaneous radiation monitoring extended over a wide area such as Fukushima prefecture and eastern Japan, in contrast to other conventional carborne survey systems lacking scalability.

As the situation became stabilized, the main interest in measurements moved to the long-term (several tens of years) monitoring of radiation from radioactive materials remaining in the environment. KURAMA-II [2] was developed for such purpose by introducing the concept of continuous monitoring from vehicles moving around residential areas, such as local buses and postal motorcycles. The ruggedness, stability, autonomous operation and compactness were well taken into consideration in its design, and an additional measurement capability of pulse-height information along with location data was also introduced. KURAMA-II has been successfully introduced to the continuous monitoring in residential areas and other monitoring activities [3–6], and the accumulated knowledge is summarized and standardized in the radiation monitoring in Japan [7].

In this paper, the outline and the current status of KURAMA-II along with some results from its applications are introduced.

KURAMA-II

Measurement Unit

KURAMA-II consists of a group of measurement units connected over the network [2]. Each measurement unit is based on CompactRIO by National Instruments to obtain sufficient ruggedness, stability, compactness, and autonomous operation feature. The radiation-detection part of KURAMA-II is the C12137 series by Hamamatsu Photonics [8], a MPPC-based CsI(Tl) detector series characterized by its compactness, high efficiency, direct ADC output and USB bus power operation. The ambient air dose rate, $H^*(10)$, is calculated from the pulse height spectrum obtained for each measurement point by using the G(E) function method [9–11]. Since the energy dependence of detector efficiency is properly compensated by G(E) function, more reliable results for environmental radiations are expected than those from GM counters, which just count the number of incoming γ-rays without identifying the energy of each γ-ray.

Data Management in KURAMA-II

The file transfer protocol used in KURAMA-II has been designed to comply with the standard protocols widely used in today's networks, such as Web Services. In this protocol, two timestamped files, a text file for the air dose rates and a 32-bit binary file for the pulse-height spectra, are separately produced for every three measurement points. Generated files are transferred to a remote server by the POST method. All communications between measurement units and a remote server are based on RESTful API. Unsent files inside a measurement unit are archived as a single zip file for the next available network connection. The server generates the data files of radiation and energy spectrum based on the received data for respective measurement units. A new visu-

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alization scheme for KURAMA-II has been developed on GIS map scheme served by Geospatial Information Authority of Japan [12](Fig. 1) in addition to the current cloud data storage service based on ownCloud [13]. Further analyses, such as the reconstruction of the pulse height spectrum, are available for Grid Square Statistics defined by the Statistics Bureau of Japan (Fig. 2). This scheme is available not only as an on-premise software but also as a cloud base service, intending to introduce low-cost subscription plans for users in small groups.

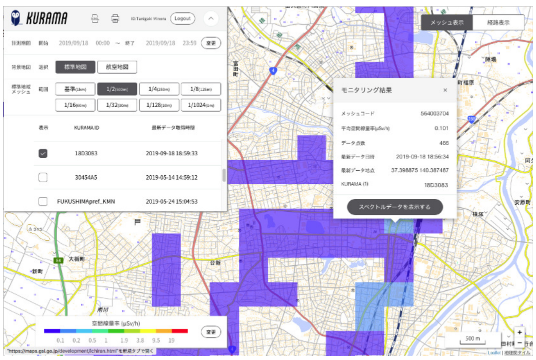

Figure 1: A typical radiation map based on a new visualization scheme developed on the GIS map scheme by Geospatial Information Authority, Japan [12].

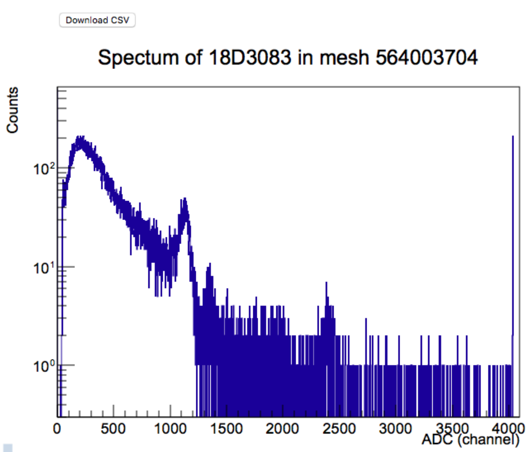

Figure 2: A typical pulse height spectrum reconstructed from the data within a mesh displayed on the map. This function is developed with JSROOT [14]. The numerical data is available via the "Download CSV" button. This spectrum is reconstructed from the data in the center region of Koriyama city in Sep. 2019. The peaks of γ-rays of ^{134}Cs ($T_{1/2}$=2 y) are almost vanished, while those of ^{137}Cs ($T_{1/2}$=30 y, around 1150 ch) and ^{40}K (natural isotope, around 2400 ch) are still clearly observed.

APPLICATIONS OF KURAMA-II

Recovery of Farmlands near Fukushima Daiichi Nuclear Power Plant

A differential measurement technique has been developed for the evaluation of soil contamination [15, 16] based on high flexibility in the hardware configuration of KURAMA-II. In this technique, the contribution from surroundings measured by a nondirectional detector is subtracted from the intensity measured by a detector collimated towards the ground surface to obtain only the contribution from the radioactivity on the ground. For the practical application of this technique, a three- year project starting from the fiscal year of 2018 has been approved by Ministry of Agriculture, Forestry and Fisheries, Japan, to build a "robot" for the recovery of contaminated farmlands (Fig. 3). This "robot" will be a faming tractor equipped with KURAMA-II for radioactivity, an optical spectrum sensor to measure the fertility and chemical property of soil, and the high precision guidance system for the operation of tractor in farmlands.

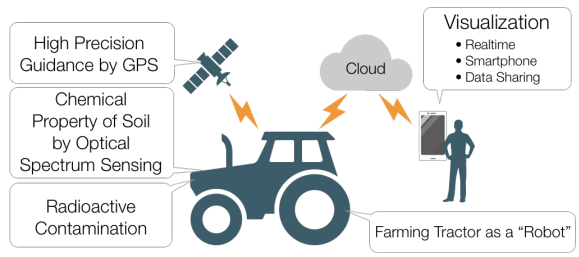

Figure 3: A conceptual scheme of a "robot" for the recovery of farmlands.

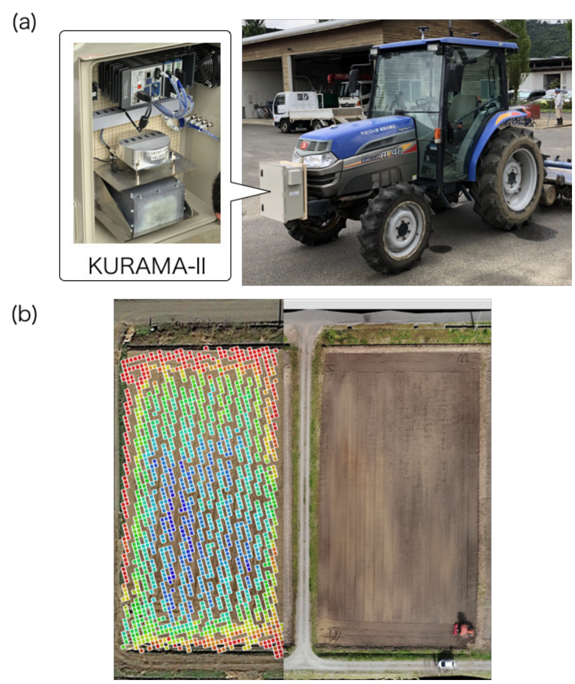

Figure 4: (a) An experimetal "robot" tractor equipped with KURAMA-II for the evaluation of soil contamination. (b) A typical example of the visualization of relative soil-contamination density (left) and the orthochromatic image (right) of this experimental farmland. Ununiform distribution of imported soil (clean, but barren) in the center region is clearly observed.

The simultaneous visualization of radioactivities and fertility of farmlands on the smart phones and tablet-type de-

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vices will be performed via a cloud service (Fig. 4). Numerical data of radioactivity and fertility along with their positioning data will be also served for controlled fertilization machines or plowing machines to help farmers to recover their farmlands.

Development of a Single-board KURAMA-II

In cases of extreme conditions including a nuclear disaster in progress, the prompt establishment of radiation monitoring is required to minimize the opportunity lost and to ensure the leading time for establishing more reliable, concrete monitoring scheme towards the incident. Therefore, we have now been porting KURAMA-II to a single-board computer to extend its applications to such cases. A single-board computer based KURAMA-II is designed to minimize its cost, size, and power consumption rather than to maximize reliability, durability, and precision. Many single-board KURAMA-IIs will be deployed as disposable probes to the target area (e.g. areas extremely contaminated by radioactivity) and transmit the data via mesh-network based on LPWA. This cheap, simplified KURAMA-II will also be an affordable tool for education to obtain a better understanding of radiation monitoring to the public.

The development of a single-board based KURAMA-II has started as a two-year commissioned project of Nuclear Regulation Authority, Japan since 2019. Spresense from Sony [17] is chosen as the platform because of its integrated GPS, audio processing capability applicable to pulse height analysis, a powerful multi-core microcontroller, and its low power consumption. Thanks to the extending and competitive market of MPPC module, a low-cost CsI(Tl) detector based on the analog part of C12137 will be developed for this KURAMA-II. The output pulse signals from this detector are processed by an ADC for the audio signal in Spresense. As for network communication, we expect to use Wi-SUN [18] as the LPWA network for this KURAMA-II. Wi-SUN is the de facto standard of network communications for smart watt-meters for the electricity in Japan. Wi-SUN FAN [19], the autonomous mesh-network protocol of Wi-SUN, is now under implementation to commercial chipsets, we will start field tests for Wi-SUN fan protocol with the chip-developer as soon as the chipset is released.

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