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Development of KURAMA-II and its operation in Fukushima

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ABSTRACT

A carborne survey system, named as KURAMA (Kyoto University RAdiation MApping system), was developed as a response to the nuclear accident at TEPCO Fukushima Daiichi Nuclear Power Plant in 2011. Now the system has evolved into KURAMA-II, characterized by its compactness, autonomous operation, and acquisition of pulse-height spectrum data. A two-year field test of radiation monitoring by KURAMA-II on local buses, performed by Kyoto University, has successfully proceeded to the phase of official operation by the Fukushima prefectural government, supported by Kyoto University and JAEA (Japan Atomic Energy Agency). An outline and the current status of KURAMA-II, including some results of the continuous monitoring by KURAMA-II on local buses in Fukushima, are introduced.

1. Introduction

The magnitude-9 earthquake in eastern Japan and the following massive tsunami caused a serious nuclear disaster of Fukushima Daiichi nuclear power plant. Serious contamination was caused by radioactive isotopes in Fukushima and surrounding prefectures. KURAMA [1] was developed to overcome the difficulties in radiation surveys and to establish air dose-rate maps during and after the present incident. KURAMA was designed based on consumer products, and enabled a large number of in-vehicle apparatus to be prepared within a short period owing to its high flexibility in the configuration of data-processing hubs or monitoring cars. KURAMA has been successfully applied to various activities in the radiation measurements and the compilation of radiation maps in Fukushima and surrounding areas.

As the situation was stabilized, the main interest in measurements moves to the tracking of the radioactive materials that have already been released into the environment surrounding the residential areas. KURAMA is not suitable for such purposes. Even though KURAMA enables measurements with a large number of monitoring cars over a wide area at one time, it still requires a trained operator and a driver in each monitoring vehicle. This means that a huge amount of resources and efforts will be required once the surveillance is changed into long-term (several tens years) and detailed monitoring in residential areas. Such monitoring can be realized efficiently if vehicles that periodically move around the residential areas, such as city buses, delivery vans or motorcycles for mail delivery, have compact and full-automated KURAMAs onboard. KURAMA-II is designed for such a purpose.

In this paper, a system outline and the development of KURAMA-II as well as the results of continuous monitoring using KURAMA-II will be introduced.

2. System outline of KURAMA-II

The system outline of KURAMA-II is shown in Fig. 1. KURAMA-II basically stands on the architecture of KURAMA [1], but the in-vehicle part has been totally re-designed. In KURAMA, a notebook PC was used in an in-vehicle unit, but KURAMA-II is based on the CompactRIO series of National Instruments [2] to obtain better toughness, stability and compactness. The 3G/GPS module for CompactRIO by SEA [3] provides time and location data as well as connection to a 3G network. The radiation detection part has been replaced from the conventional NaI survey meter to the C12137 detector series by Hamamatsu Photonics [4]. This CsI detector series is characterized by its compactness, high efficiency, direct ADC output and USB bus power operation. The direct ADC output enables one to obtain γ-ray pulse height spectra during operation. The specifications of C12137 series used in KURAMA-II are summarized in Table 1. All of the components for the in-vehicle part are placed in a small tool box for a better handling (Fig. 2).

Data communication between C12137 and CompactRIO is achieved using the NI-VISA USB RAW mode. C12137 sends a chunk of binary data every 100 ms, consisting of the number of detected

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0168-9002/

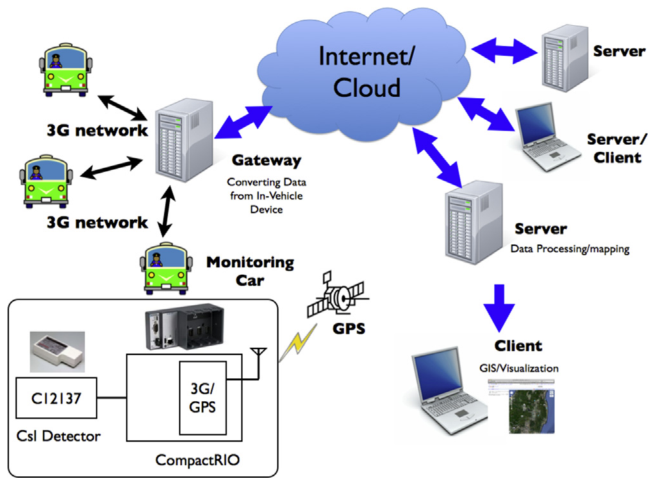

Fig. 1. System outline of KURAMA-II. The scheme is basically the same as that of KURAMA, but a gateway server is introduced for the conversion of data chunks from in-vehicle units to data files shared over Dropbox [5] due to no support of Dropbox on CompactRIO.

Table 1
Specification of the C12137 series [4] used for KURAMA-II. Two types of C12137 series are used, depending on the measurement conditions, such as the expected range of air dose rate.

Type	C12137-00	C12137-01
Scintillator	CsI(Tl)	
Scintillator size	$13 \times 13 \times 20$ mm	$38 \times 38 \times 25$ mm
Energy resolution (662 keV)	8%	8.5%
Counting efficiency (662 keV, 0.01 μSv/h)	40 cpm	400 cpm
Detecting device	MPPC	

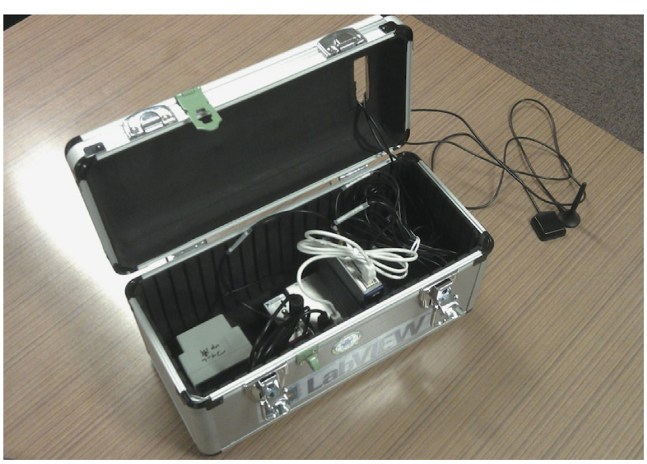

Fig. 2. In-vehicle part of KURAMA-II. The components are placed in a small tool box (34.5 cm $\times$ 17.5 cm $\times$ 19.5 cm) for the better handling. This tool box is made of 1 cm thick balsa wood plates covered with thin aluminum sheets, and no effective shielding towards typical γ-rays in environment.

γ-rays, a series of 16-bit ADC data of detected γ-rays, and the temperature inside C12137. A 4096 ch pulse-height spectrum is constructed every 100 ms from the obtained 16-bit ADC data inside CompactRIO. γ-rays whose energy exceeds the upper limit of ADC (around 2.8 MeV) are treated as the upper-limit energy of ADC in the construction of pulse-height spectra.

In KURAMA-II, the air dose rate is obtained from the pulse-height spectrum by using spectrum-dose conversion operators, the so-called $G(E)$ function method [6,7]. In this method, the air dose rate is directly obtained from the pulse-height spectrum without any spectrum analysis of the complex spectrum of the environmental γ-rays. In the $G(E)$ function method, the total dose D under the existence of a mixed flux of γ-ray with different energies $E_0, E_1, E_2, \ldots$ ($\phi(E_0), \phi(E_1), \phi(E_2) \ldots$) is given as

$$
\begin{aligned}
D &= \sum_{i=0} \phi(E_i) h(E_i) \\
&= \sum_{i=0} \int_0^\infty \phi(E_i) n(E, E_i) G(E)\, dE \\
&= \int_0^\infty \sum_{i=0} \phi(E_i) n(E, E_i) G(E)\, dE \\
&= \int_0^\infty N(E) G(E)\, dE
\end{aligned}
\tag{1}
$$

under the assumption of the existence of a weighting function, $G(E)$, satisfying the following integral equation:

$$h(E_0) = \int_0^\infty n(E, E_0) G(E)\, dE \tag{2}$$

where $h(E_0)$ is the conversion coefficient for γ-rays of monochromatic energy E_0, and $n(E, E_0)$ is the response function of the detector, $N(E)$ is the measured pulse-height spectrum, respectively.

The Japanese government recommends the ambient dose equivalent, $H^*(10)$, as the operational quantity of area monitoring. This time, $G(E)$ functions for $H^*(10)$ were determined by the Japan Atomic Energy Agency (JAEA) group for C12137-00 and C12137-01 (Fig. 3). Details concerning the determination of these $G(E)$ functions and the characteristics of KURAMA-II on radiation detection are available in Ref. [8].

KURAMA-II has a built-in function to observe a photo peak in the pulse-height spectrum, since the gain stability of the detector is directly connected to the stability and reliability of the obtained air dose rate. The 796 keV peak of ^{134}Cs, which is typically observed as a well isolated peak in the pulse-height spectrum of Fukushima area, is used to monitor the gain shift during operation. Up to now, the peak drift is at most 3% throughout the operation for 1 year. This corresponds to 5% of the drift at most in the air dose rate, one-third of the tolerance for typical portable survey meters used for the air dose rate measurements in Fukushima.

The air dose rate and the pulse-height spectrum for each measurement point are collected in the current KURAMA-II scheme. A simple file-transfer protocol based on RESTful was developed for KURAMA-II, since Dropbox does not currently support VxWorks, the operating system of CompactRIO.

In this protocol, a chunk of data as a timestamped file is produced for every three measuring points. Then, every chunk is transferred to a remote "gateway server" by the POST method. The gateway server returns the name list of chunks that are successfully received. The chunks in CompactRIO will not be deleted unless those names are confirmed in the returned list from the gateway server. Unsent chunks are archived at every one hundred of them as a single zip file, and these are sent as soon as the network connection is recovered. Timestamped files of the air dose rate and the pulse height spectrum are separately produced. In the case of the air dose rate, Date/Time, location data, the air dose rate, the temperature of the detector, are written into a timestamped text file. Sometimes additional data are also written into this file upon user's request for special purposes. An example of such special data is the air dose rate calculated from the specific energy region, which is requested by one of the user group for their use. The gateway server combines received files to the data file, which is shared by remote servers using a cloud-based file sharing service, Dropbox [5], as was done in original KURAMA. In the case of pulse-height spectrum, the date/time, location data, air dose rate, list of channel numbers and its counts that are non-zero counting are written into a timestamped binary file. The gateway server records the data of the binary files to a SQL database