DEVELOPMENT OF A NETWORK-BASED PERSONAL DOSIMETRY SYSTEM, KURAMA-micro

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Abstract

KURAMA-micro, a personal dosimetry system with network and positioning capabilities, is developed for the continuous monitoring of radiation exposure of individual in a large group, based on their action histories. Typical target users are the residents returning to their hometown after decontamination, and the workers involved in the decomissioning of the Fukushima Daiichi nuclear power plant. A KURAMA-micro unit consists of a semiconductor dosimeter and a compact DAQ board with a GPS module and a ZigBee module. Each unit records radiation data tagged with their measurement time and locations, and uploads the data to the server over a ZigBee-based network once each unit comes near the access point installed in the area of daily activities of users. Location data are basically obtained by a GPS unit, and an additional radio beacon scheme using ZigBee broadcast protocol is also used for the indoor positioning. A field test of the prototype of KURAMA-micro was performed in Fukushima city, and the radiation trends were successfully observed.

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] and KURAMA-II [2] were developed to overcome the difficulties in radiation surveys and to establish air dose-rate maps during and after the present incident. KURAMA has been successfully applied to various activities in the radiation measurements and the compilation of radiation maps in Fukushima and surrounding areas. KURAMA-II, an advanced version of KURAMA with autonomous operation and pulse height spectra measurement, has been used to establish the continuous monitoring scheme in residential areas in Fukushima prefecture. Fifty local buses and official cars equipped with KURAMA-II have been continuously operated in Fukushima prefecture, and radiation maps have been released to the public on weekly-basis. The results from KURAMA-II also contribute the predictions of air dose rates of the future in Fukushima.

Along with such wide-scale monitoring, the importance of more personalized monitoring intending to track the actual exposure of individual to the radiation are recognized to clarify the dependence of radiation exposures to human activities. For example, it is well known that the indoor radiation exposure becomes lower than outdoors, but the time length of stay indoors/outdoors vary depending on one's occupation, age, place to live etc. To clarify what kind of activities cause the higher radiation exposure is important to establish effective measures to minimize the radiation exposure. As the recovery from the nuclear accident in Fukushima progresses, strong demands of such personalized monitoring arise for a large group with higher risk of radiation exposure, such as the residents returning to their hometown after decontamination, or the workers involved in the decomissioning of the Fukushima Daiichi nuclear power plant.

For such purpose, personal dosimeters that measure the cumulative radiation dose, such as film badges, electronic pocket dosimeters, have been widely used, but the lack of positioning and time information made difficult to analyze in the view point of the human activities. Additionally, the difficulty in collecting data periodically from a large number of people obstruct the analysis of such data to extract the general tendency of radiation exposure towards human activities.

KURAMA-micro, a personal dosimetry system with network and positioning capability, is developed for such purpose. KURAMA-micro consists of a semiconductor dosimeter and a DAQ board with GPS and ZigBee modules. The data of KURAMA-micro is collected via an ad-hoc ZigBee based network to minimize the troubles of users. The development of a prototype KURAMA-micro is finished and field tests are on the way. In this paper, the outline of KURAMA-micro and the results from a field test in Fukushima are introduced.

SYSTEM OUTLINE OF KURAMA-micro

KURAMA-micro stands on a similar concept as claimed by KURAMA/KURAMA-II, and intends to be the alternative choice of conventional personal dosimeters. Therefore, the system must overcome the difficulties arising from its usage. For example, the unit must be comparable in size to other personal dosimeters, and the operating time should be long comparable to the replacement period of conventional film badges, typically one month. Therefore KURAMA-micro is designed to achieve better performance on power-consumption or sufficient compactness rather than on the detection efficiency or the measurement precision.

KURAMA-micro consists of the radiation detection part and the DAQ part (Fig. 1). The radiation detection part is a conventional accumulated radiation dosimeter with I2C connection to the DAQ part. The DAQ part has an I2C interface for the radiation detection part, a GPS unit for positioning, and a ZigBee unit for the data communication.

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This ZigBee unit is also used for a supplemental positioning where the radio waves from GPS satellites are not available.

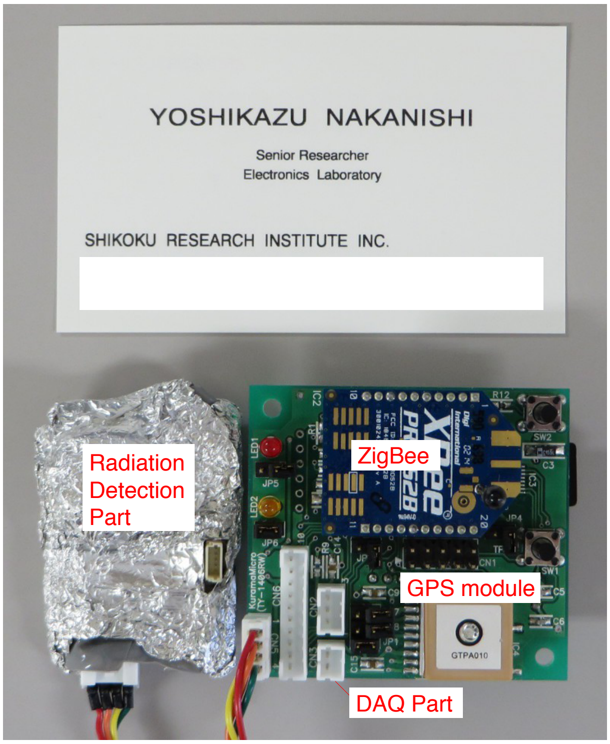

Figure 1: A prototype KURAMA-micro unit. The board on the right is the DAQ part based on OpenATOMS architecture. The left part shielded by aluminum foil is the radiation detection part. Both are implemented into a box of business card size. The power required for the unit is managed by a 3.7 V rechargeable Li-ion battery.

The radiation detection part of KURAMA-micro consists of a typical semiconductor detector, charge-amplifier, shaping amplifier, and a microprocessor with ADC capability. A conventional photodiode (Hamamatsu S6775) is used as a semiconductor detector. The charge amplifier and shaping amplifier are configured by using Smart Analog series of Renesas Electronics [3]. Smart Analog is a programmable analog IC designed for processing small sensor signals. This IC includes several amplifiers with programmable gain, general-purpose operational amplifiers, high-pass and low-pass filters, and DACs, and those connections and operation modes are programmable. Additionally, Smart Analog has several low power consumption modes, in which the circuits in the IC are operated intermittently or turned off partially upon user's settings. Such low power mode is useful for the devices required for the low-power operation such like KURAMA-micro. Each pulse from the Smart Analog IC is sent to ADC in the microprocessor, then accumulated as a pulse height spectrum. The accumulation period lasts until the request for air dose from DAQ part comes, then the accumulated air dose is calculated from this pulse height spectrum by G(E) function method [4].

The DAQ part of KURAMA-micro is based on OpenATOMS(open Advanced Topological On-demand Monitoring System) [5] developed by Shikoku Research Institute Inc. OpenATOMS is a platform developed for sensor networks in field, especially for the cases that the continuous monitoring is required for a long period under the lack of sufficient power supplies or a reliable network communication. In this platform, each sensing device is connected to a microcomputer board named as NICE(Networked Intelligent CEll). One of the features in NICE is the low power consumption by an advanced power management scheme in which the power of most part in NICE can be switched on/off by the embedded timer. With this feature, a NICE board can be operated for more than a month by a conventional dry cell. Each NICE board joins an ad hoc ZigBee network maintained by a local gateway server connected to a TCP/IP network. All the data are once collected and stored in a local server as an XML based format, then extracted by remote users or data servers upon request. Typical applications of OpenATOMS are the monitoring the ground parameters to detect landslides in mountainous areas, or the condition in hothouses for agricultural products.

These features of OpenATOMS almost satisfy the requirements of KURAMA-micro. The power management system implemented in NICE is quite useful for the minimization of power consumption in KURAMA-micro, and the data management vis the ad hoc network based on ZigBee realizes the data collection without the manipulation of users. But there are still challenges. One of the challenges in the case of KURAMA-micro is that the units do not always join the ZigBee network because each unit always move around the residential area along with the carrier. This results in a large power consumption if the continuous seek of an access point is simply allowed. Therefore, the seeking time of the network is limited based on the activities of the people carrying KURAMA-micro by using the power management capability of NICE. For example, the seeking time is limited to the daytime of weekdays in the case of schoolchildren, expecting the attendance of their classrooms and the connection to the access points placed at the classrooms.

Another challenge in KURAMA-micro is the positioning scheme where the radio waves from GPS satellites are not available, mainly indoors and underpasses. This time, radio beacons using ZigBee broadcast protocol are used as the alternative positioning for this purpose. These ZigBee-based beacons are settled place by place, and the location of the measurement is treated as that of received beacon. This scheme is not only enables the approximated positioning in indoors and underpasses, but also effective to improve the accuracy of the height information in buildings to distinguish the difference of radiation exposure in floor level. The accuracy in height is generally very poor in GPS, poor enough not to distinguish the floor level.

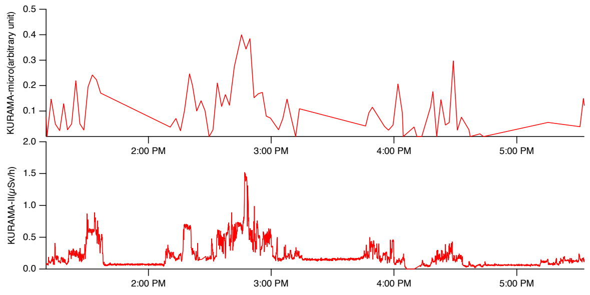

Figure 2: The time-domain trend of air dose rate obtained by KURAMA-micro(upper graph) and that obtained by KURAMA-II(lower graph) for comparison. The measurement period for KURAMA-micro and KURAMA-II are one minute and three seconds, respectively. The air dose rate from KURAMA-micro is described in arbitrary units because the absolute calibration for the unit is not performed at that time.

TEST OPERATION IN FUKUSHIMA

To confirm the concept of KURAMA-micro, a field test of a prototype KURAMA-micro carried by an examinee was performed in the center area of Fukushima city. The purpose of this field test was to examine whether KURAMA-micro actually tracks the radiation exposure to a person under activities of daily living. During the field test, the examinee strolled around the center of Fukushima city, mainly outdoors and occasionally inside the building. The examinee was accompanied by a person measuring the air dose rate by KURAMA-II for comparison. The measurement period of KURAMA-micro was set to 1 minute instead of 10 minutes for detailed analysis of the effect from surrounding condition to the radiation measurement.

The radiation trends of KURAMA-micro and KURAMA-II in time domain is shown in Fig. 2. A moderate correlation was found between the results of both systems. Some differences observed in the trends were caused by "micro hot spots" that were occasionally observed in Fukushima city, such as remaining contamination at hedges along the road. Such small hot spots produce a localized radiation field, which often cause the difference on the air doses of examinee and the accompanied person. Other differences were due to the improper sequence implement in this prototype of KURAMA-micro. DAQ board was programmed not to request the radiation data to the radiation detection part until the positioning had been determined, so the air dose data was often kept accumulated beyond the normal request time period. The positioning by GPS frequently failed due to the buildings along the street, therefore the request period tended to be longer than that was set.

The radiation map generated from the result of KURAMA-micro was compared with that from the result of KURAMA-II units on local buses(Fig. 3). In the central area of Fukushima city, a radiation map with the grid size of 100 m × 100 m is generated by KURAMA-II units on local buses on a weekly basis [6]. Through the averaging procedure of KURAMA-micro data to 100 m × 100 m grid, differences caused by "micro hot spots" and intermittent failures of GPS were averaged. These maps are similar except several regions, and these were mainly identified as the effect of measurement points such as inside the building or the underpasses of large roads.

CURRENT STATUS AND FUTURE PROSPECTS

Currently, KURAMA-micro is under development, mainly for the reduction of interference by incoming noise. The reduction of such noise is crucial for the semiconductor detectors since they usually have a high impedance charge amplifier in their front end. As soon as the sufficient noise reduction is achieved, several extended field tests will be performed. Along with the noise reduction, tunings for the power reduction is on the way, such as the optimization in the power management of the GPS module. As for the current prototype KURAMA-micro, the operation time reaches around three weeks with 3.7V 3100 mAh battery.

One of the expected applications of KURAMA-micro is the personal dose monitoring of school children(Fig. 4). In this application, a KURAMA-micro carried by a schoolchild collects the radiation data and positioning data throughout the day. The positioning data is basically collected by a GPS unit in KURAMA-micro, and radio beacon units using ZigBee broadcast protocols are placed in the public buildings in the school district and in houses of school children. Such radio beacons are expected to be placed easier because the area of the activities of school children is mainly in the school district. The frequency of data collection is planned 10 min, to reduce the power consumption and not to disclose the activities of school children too much from the viewpoint of privacy. The data accumulated by each KURAMA-micro unit is collected via the access point in classrooms of their school while schoolchildren stays in their school. The col-

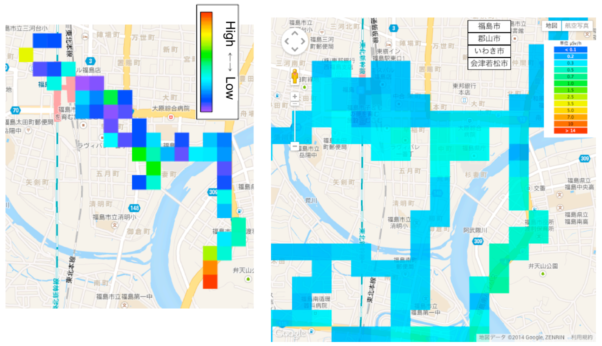

Figure 3: The air dose rate map from the data of KURAMA-micro(left side) and that from KURAMA-II on local buses(right side) at the same measurement period. The values were averaged for every 100 m × 100 m. The air dose rate from KURAMA-micro is described in arbitrary units because the absolute calibration for the unit is not performed at that time.

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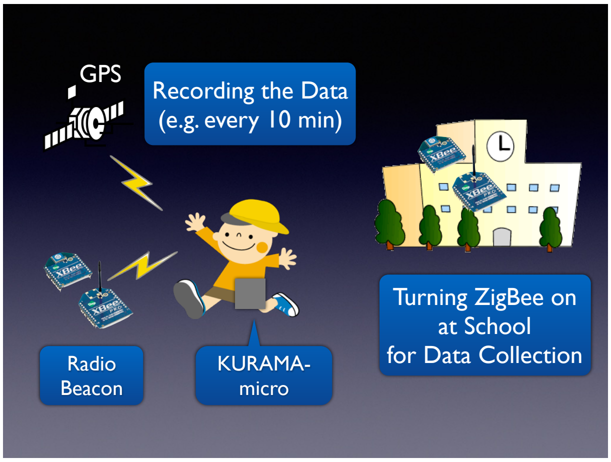

Figure 4: An expected operation of KURAMA-micro.

lection time for all the data of schoolchildren in a class is estimated to be several hours by taking into account the transmission speed of ZigBee, almost the same as the average staying time of school children in a classroom. KURAMA-micro units are replaced every month, as that in the case of other conventional dosimeters like film badges.

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