J-PARC Main Ring 向け Raspberry Pi と XBee（近距離無線）で組んだ放射線モニタ

RADIATION DOSE MONITOR SYSTEM BASED ON RASPBERRY-PI AND XBEE FOR J-PARC MAIN RING

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Abstract

The real-time radiation dose monitor system is developed in J-PARC to realize quick feedback of exposed dose upon individual workers in radiation environment, especially in accelerator tunnel. The system is based on EPICS, and the system hardware is mainly composed of Raspberry-pi and XBee wireless communication module. The system is designed to monitor radiation dose values from a dose meter, to transfer them to a local PC wirelessly in a distance. The system has been demonstrated in the J-PARC Main Ring tunnel, and the result shows the advantages and disadvantages of this system in the radiation environment.

1. Introduction

J–PARC (Japan Proton Accelerator Research Complex) is a high intensity proton accelerator facility. It has three proton accelerators (linac, rapid-cycle synchrotron, and main ring synchrotron) and three research facilities (materials and life science facility, neutrino facility, and hadron facility). Using MW-class high power proton beams, generated secondary particles (neutrons, muons, neutrinos and mesons) are used for various advance studies [1,2].

As Fig. 1 shows, accelerator workers sometimes must work in a high radiation environment. However, the existing radiation dose monitoring system in J-PARC is not a real-time system. It tells the total dose of individual worker accumulated during the work, only when a worker leaves a radiation-controlled area. A new monitor system is desirable that can collect and display dose of a worker in real time, even when a worker is still in a radiation-controlled area.

We have developed a prototype radiation dose monitoring system. According to the system, we can monitor real-time dose levels of a worker in a radiation-controlled area. This feature is essential to avoid unexpected dose during radiation works.

This report describes hardware and software details of the prototype system, a report of system test in an accelerator tunnel, and discussions are given.

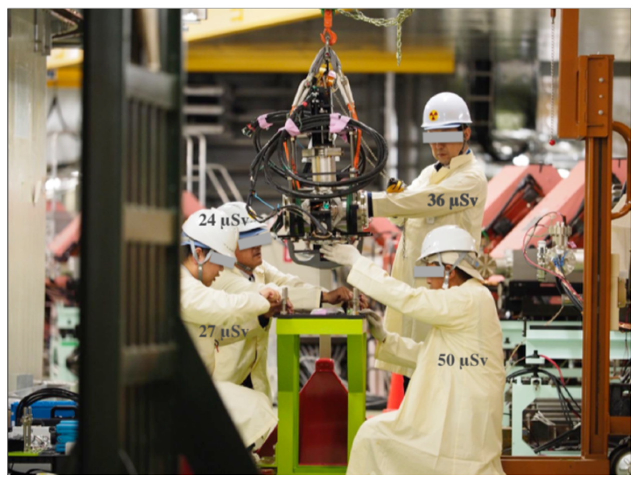

Figure 1: Image of workers in high radiation environment.

2. Overall System

2.1 Hardware – Design

The goals of the real-time radiation dose monitor system are: (a) to measure exposed radiation doses to a worker in real-time and (b) to supervise doses remotely on a PC in radiation-controlled area. To achieve the objectives, we use the technologies of ZigBee wireless scheme with XBee modules [3-5] and Raspberry Pi [6]. XBee modules can realize wireless communication to transfer real-time dose data to a PC. Raspberry Pi is a mobile device and can be a core processor for dose measurement, as well as for a PC.

The hardware design of the whole system is shown in Fig. 2. The system consists of a sensor part and (b) a supervisor part. The sensor part includes a radiation dose meter, a Raspberry Pi Zero and a XBee (Router) module. The radiation dose meter works every one

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second. The Raspberry Pi Zero receives dose data of the meter through a USB port, then send to supervisor part using a XBee (Router) module.

The supervisor part includes a local PC with a touch display and a XBee (Coordinator) module. The local PC receives data from sensor part using a XBee (Coordinator) module, then the real-time doses can be displayed on the touch display.

We adopted two modern technologies. For short-term wireless communication, we introduced XBee modules based on ZigBee protocol[3]. ZigBee defines three different device types of XBee: coordinator, router and end-device. The coordinator device starts the network, selecting the channel and Personal Area network ID (PAN ID), which are used to identify a Xbee wireless network. In a network, there must be only one coordinator[4]. Routers and end-devices can join the network with the channel and the PAN ID. They can send and receive messages to/from a coordinator. As in Fig. 2, as the first step, our system has one coordinator and only one router. The router acts as an end-device.

Another technology is Raspberry Pi[6]. Because of its portability and low cost, we use it at both the sensor part and the supervisor part. In addition, Raspberry Pi has General Purpose Input-Output (GPIO) connector and ports for other accessories (such as camera, infrared camera, official display, etc.). We use GPIO connectors for a XBee module. A camera and a touch display screen are connected using accessory ports (see 3.1).

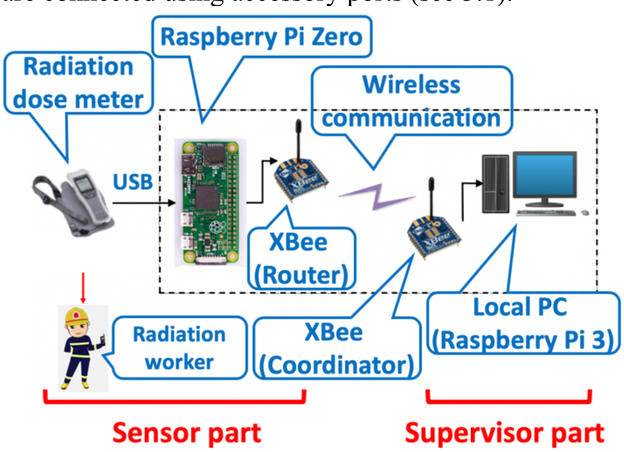

Figure 2: The hardware of radiation dose monitor system.

2.2 Software

EPICS (Experimental Physics and Industrial Control System) is a software framework to develop control systems. It has been developed and maintained by world-wide accelerator community [7]. Though EPICS has been developed for a large accelerator like J-PARC [8], it is also applicable in small systems. We decided to use EPICS on two Raspberry Pies in the system. The operating system is Raspbian, which is Debian based Linux for Raspberry Pi. More details are given in 4.2.

In addition to EPICS, we introduced other software resources. A free software XCTU, developed and distributed by Digi[9], is used to configure the XBee parameters and to test the communication between XBee modules. Python libraries are used to use various functions for a camera and a touch screen display.

3. Demonstration

3.1 Hardware – Real Implementation

A prototype of real-time radiation dose monitor system was developed. The real implementation is shown in Fig. 3. The left side part shows the sensor part, right side part shows the supervisor part.

On the real sensor part, it includes a commercial radiation dose meter (PDR303), an integrated package with a two-line indicator and a portable power supply. Inside the package, Raspberry Pi Zero and a XBee (Router) module are included. The two-line indicator can show the dose data from the sensor. The portable power supply can provide power to a Raspberry Pi and a XBee (Router) module.

On the supervisor part, Raspberry Pi 3, a XBee (Coordinator) module, a camera and a touch display screen are all integrated to make it easier to carry. In an operation mode, the touch display screen shows camera views. As in Fig. 4 and Fig. 5, values of real-time dose rate and accumulated dose are indicated over the camera view. We can take photos (save screen-shots) with dose values manually. The portable power supply can provide power to the whole supervisor part.

Figure 3: Real implementation of the system.

3.2 System Test in J-PARC Main Ring Tunnel

J-PARC Main Ring is a 30GeV slow cycling synchrotron. It is the furthest downstream and physically the largest accelerator at J-PARC [10].

We tested the real-time radiation dose monitor system in J-PARC Main Ring tunnel. When a worker with the sensor part approaches a possibly radiated component, a supervisor person with the supervisor part can monitor real-time doses of the worker. Figure 4 shows a short distance test of the system. Wireless transfer of dose data and watching them in an accelerator tunnel were demonstrated successfully.

Figure 5 shows a long-distance test of the system.

The worker with the sensor part arrives at 20 meters away from the supervisor person. Wireless transfer of radiation dose and monitoring dose on supervisor part were demonstrated successfully.

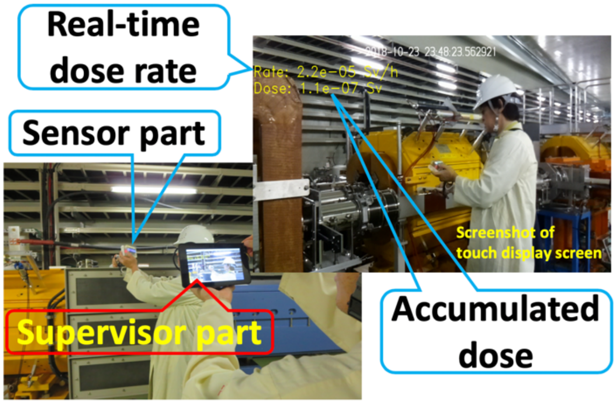

Figure 4: Short distance test of the system.

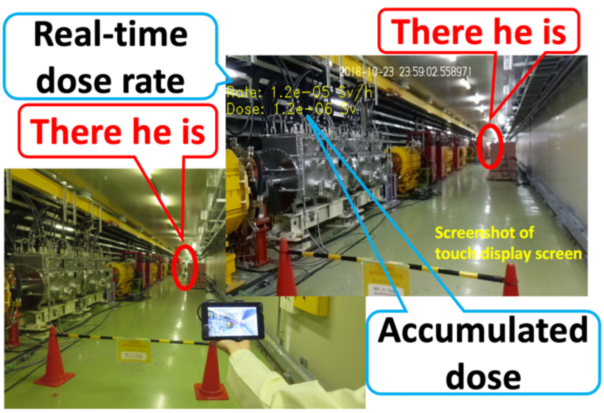

Figure 5: Long distance test of the system.

4. Discussion

4.1 Short-Term Wireless Technology

Nowadays, there are three popular technologies of short-term wireless: Wi-Fi, Bluetooth and ZigBee. Three technologies are compared in Table 1.

According to Table 1, we can see many advantages of ZigBee wireless technology, such as long-distance communication, low power consumption, low cost, and easy to learn and use.

High power radio wave may cause incorrect counts in radiation sensor. Some devices we have tested show this symptom. This is another reason why we choose ZigBee for this system, because it only has a slight impact or no impact on the radiation sensor.

Table 1: The Comparison between ZigBee, Bluetooth and Wi-Fi

Specification	ZigBee	Bluetooth	Wi-Fi
Operating Frequency band (GHz)	0.868/0.915; 2.4	2.4	2.4 and 5
Data Rate (Mb/s)	0.25	1-3	600-9608
Range (m)	10-100+	1-10	100+
Power Consumption	Ultra-low	Medium	High
Cost	Low	Medium	High
Complexity	Simple	Complex	Complex

4.2 EPICS on Raspberry Pi

Trials to install EPICS on Raspberry Pi have been carried out by several groups. The wheezy-raspbian distribution has all the tools necessary to build EPICS base[11]. Our group also contributed to demonstrate EPICS on Raspberry Pi in 2018[12].

For the real-time radiation dose monitor system, "StreamDevice" and "AsynDriver" are used for XBee modules with serial communication. To use Raspberry Pi's GPIOs, "devgpio" is used. The tool "procServ" is used to realize auto-start function of EPICS. These device supports and tools are standard in the EPICS community, and we can find much information online.

4.3 Future Plan

Considering the result of system test and radiation workers comments, some improvements will be made in the future.

- Up to now, the system has one sensor part only. We plan to increase the number of sensor parts. To realize, we must develop device-level software to handle many routers (serial communication ports) with a coordinator.
- The cost of PDR303 radiation sensor is as high as about 90,000 JPY. In addition, a PDR 303 is large and inconvenient to be carried in to an accelerator tunnel. We will try to find a cheaper and smaller radiation sensor which can be integrated into the sensor part's package.
- An alarm system is preferable. It will generate alarm signals, audible sounds and indications on a screen, when the radiation dose exceeds pre-defined threshold values.

5. Summary

We have developed the prototype of real-time radiation dose monitor system and tested it in J-PARC Main Ring tunnel. The system is portable to be carried into an accelerator tunnel. It works successfully with

XBee wireless modules, even the distance between the sensor part and the supervisor part is as far as 20 meters.

In the future, we will improve current prototype to an operational model. We believe the system is helpful for radiation workers to avoid unexpected radiation during the whole radiation work.

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