Remote Sensing of Radiation Dose Rate by Customizing an Autonomous Robot

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Abstract. Distribution of radiation dose was measured by customizing an autonomous cleaning robot “Roomba” and a scintillation counter. The robot was used as a vehicle carrying the scintillation survey meter, and was additionally equipped with an H8 micro computer to remote-control the vehicle and to send measured data. The data obtained were arranged with position data, and then the distribution map of the radiation dose rate was produced. Manual, programmed and autonomous driving tests were conducted, and all performances were verified. That is, for each operational mode, the measurements both with moving and with discrete moving were tried in and outside of a room. Consequently, it has been confirmed that remote sensing of radiation dose rate is possible by customizing a robot on market.

1. Introduction

Robots used in hazardous environments have been studied and developed for nuclear industry, disaster relief and military usage for long time. Especially robots in nuclear industries have been applied for many purposes in practical operation [1]-[3]. In the fields of military and disaster relief, the most famous robot is “PackBot” produced by iRobot Co. More than 3000 PackBots are currently on station in Iraq and Afghanistan [4]. However each robot has special specification, namely for high level radiation or for travelling over the rubble and so on. Therefore these robots used in extreme environments cannot be used by anyone anywhere at any given time. Furthermore the price of PackBot is said to be 120 thousands dollars [5]. On the other hand, regarding home robot, more than 6 million sets of a cleaning robot “Roomba” have been sold so far [6], and the price has become affordable.

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In low radiation level area, for example, in Ningyo-toge Environmental Engineering Center of Japan Atomic Energy Agency and medical facilities, it is important to detect subtle indication in early stage by means of daily inspection and take measures before occurrence of unusual event in addition to a periodic examination. Some of the present authors have conducted a trial measuring of radiation dose rate distribution using equipment on the market without using specially developed equipment, and they have reported an example of the result where a cleaning robot was applied as a vehicle of a radiation survey meter [7].

After the earthquake, tsunami, and failure of cooling systems at Fukushima I Nuclear Power Plant concerning other nuclear facilities in Japan on March 11, 2011, decontamination work has been conducted, and ordinary life has been recovered. However, radiation survey is required in many places still now. The above mentioned method could be useful for investigating in school house and playground with radioactive contamination in terms of cost and convenience.

In the present paper, the measuring results of radiation dose rate and position in three modes; (1) remote manual, (2) remote programmed and (c) autonomous are reported using an additional micro computer board to handle the signal from external connecter of the cleaning robot and the scintillation counter.

2. Experimental

2.1. Equipment

Radiation survey meter used is a scintillation counter whose specifications are shown in Table 1. Geiger-Muller counter is usually used for radiation dose rate. In this study, however, the scintillation counter was applied so that higher sensitivity more than one order is required for achieve “continuous measurement method” where measurement is done with moving than for “discrete measurement method” where vehicle moves and stops to measure repeatedly. As the radiation source, a standard sample of Cesium (Cs) and a mantle mesh of lantern for camping which contains Thorium (Th) were used, and they were placed on the floor or in the test fields.

| Table 1. Specification of survey meter |
|---------------------------------------|
| Measuring ray       | $\gamma$-ray |
| Measurable range    | From background to 30.0 $\mu$Sv/h |
| Scintillater        | 25.4φ×25.4mm NaI (T1) |
| Accuracy            | Max. ±15% |
| Output range        | DC +10mV (Full scale) |
| Time constant       | 3 seconds |

A cleaning robot “Roomba” was used as the vehicle conveying the scintillation counter. Although Roomba is sold for cleaner, it is an open ware which anyone can access to the electric signals of the driving and sensing systems through an external connecter. Therefore organized activities like Packman game, in which many Roombas are handled by controlling the inner micro computer, have been held [8].

In this study, H8 micro computer board which is often used in electronics handicraft and robot Coclé was utilized for controlling the Roomba’s movement and the data communication of the radiation dose rate measurement between the vehicle and a stationary personal computer. The system structure is shown in Fig.1.

Although the operation modes are “remote manual”,” remote programmed” and “autonomous” as mentioned above, both “discrete measurement method” and “continuous measurement method” are available for the former two modes.
2.2. Measuring mode
2.2.1 Remote manual. Measured field was the campus of Tsuyama National College of Technology, and the measurement was carried out by the remote manual mode with the discrete measurement method, that is, the vehicle moved by 10 m then stopped to measure for 3 seconds repeatedly.

2.2.2 Remote programmed. In the case of the remote programmed mode, it was assumed that the mode is used for the measurement in room or corridor in building. The measurement was carried out in the two cases which are “discrete method” running and stopping to measure for 3 seconds repeatedly and continuous method” programmed a moving route of the measurement.

2.2.3 Autonomous mode. Radiation sources placed in a room were measured with the original autonomous moving function mode.

3. Result and discussion
3.1. Simulation
In the “discrete method” since measuring is conducted in a stationary, precise value is expected. The “continuous method” provides a simple moving average (SMA) of radiation dose rate for last three seconds shown in Figure 2, that is the measured values are obtained in the following equation,

\[ I_i(x_i) = \frac{1}{\Delta x} \int_{x_i-\Delta x}^{x_i} I(x)dx \]  

where \( I_i \) is the simple moving average of radiation dose rate at a coordinates \( (x, 0, h) \), \( \Delta x \) is a distance travelling for a time constant \( \Delta t \), \( I(x) \) is the distribution of radiation dose rate at a coordinates \( (x, 0, h) \). When the vehicle travel with an speed of \( v \), and \( \Delta x \) is written as \( \Delta x = v \Delta t \).
Figure 2. Schematic view of the simulation model

Figure 3 shows examples of the distributions of radiation dose rate with the discrete method \((v=0 \text{ mm/s})\) and the continuous method \((v=10 \text{ to } 200 \text{ mm/s})\) respectively. From the equation (1) and Figure 3, it is obvious that \(I_1\) obtained at high travelling speed or longer moving average time is lower than that obtained in real case namely the discrete method. Therefore the obtained data in the continuous method needs to be considered in treatment.

3.2. Moving test

In all cases of manual, programmed and autonomous mode, planned driving was confirmed. The error factor of position coordinates mainly results from wheel slip, since position data are calculated from the encoder signal in driving unit which depends on the surface condition of the floor. In the present case, an error of around 3% in moving direction was obtained for a carpet floor. Further an error due to turning direction was investigated, and an error of 5% was obtained for a case where one wheel drove and the other wheel drove in the opposite spin direction.

3.3. Measuring the distribution of radiation dose rate

3.3.1 Remote manual. Radiation dose rate was measured in the discrete method, and a value of around 0.08 \(\mu\text{Sv/h}\) was obtained. After that, the continuous method was also applied and almost same value as that in the discrete method was obtained because only natural radiation dose rate was measured.

3.3.2 Remote programmed. In Figure 4, a part of the measurement in the continuous method was shown. The indicated values at higher travelling speeds were lower than that obtained at lower
travelling speed. It is consistent with the simulation result. It is suggested that the difference was background due to natural radiation dose rate in a range from 0.07 to 0.1 $\mu$Sv/h.

3.3.3 Autonomous mode. A test result measured in continuous method with the autonomous mode is shown in Figure 6. Radiation sources were placed in an experimental field shown in Figure 5. It was verified that a map of radiation dose rate distribution is successfully created by the customized system.

![Figure 5. Overview of experimental field for the continuous measuring method](image1)

![Figure 6. The distribution of radiation dose rate obtained by the continuous measuring method](image2)

4. Conclusion

An equipment and technique, measuring the distribution of radiation dose rate with moving by utilizing a cleaning robot on market, were studied and following results were obtained.

1) Manual and programmed moving modes were additionally equipped to an autonomous cleaning robot which has an external signal connector, and the moving function as a vehicle was confirmed.
(2) A scintillation counter was equipped with the travelling vehicle, then it was verified that the remote
detection and monitoring of the radiation dose rate were capable in the discrete mode and continuous
mode.
(3) It is shown that the position of the vehicle is detected by treating the signal from the travelling
vehicle and the distribution of radiation dose rate is obtained.

Acknowledgements
A part of present project was financially supported by the Ministry of Education, Culture, Sports,
Science and Technology.

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