Real-time acquisition and correction of temperature effect in NaI(Tl) detector-based environmental gamma radiation detection device

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Abstract. Environmental radiation monitoring especially around nuclear facility is needed to ensure public protection and safety. An online radiation monitoring system which continuously detects the presence of radioactive material in the environmental is important system to quickly detects uncontrolled radioactive released to the air. In this study, a radiation detection device based-on NaI(Tl) scintillation detector as part of an online radiation monitoring system has been developed and tested. During field testing, radiation count rate, and operational condition parameters which are temperature and relative humidity was collected continuously for 3 months. Data was transferred every 10 seconds with average communication delay around 0.57 second. Total number of data points is 733,725 records, and the average count rate was 653.09 cpm ($\sigma = 81.77$). Measured temperature is between 18.9 °C and 44.3 °C, while relative humidity is between 19.4 %RH and 78.6 %RH. Experimental result shows that count rate has temperature dependence. Effect of temperature to the count rate was estimated using power equation, and then the equation is used to correct the measurement data. After correction, several peaks which indicates the presence of radioactive material other than background radiation can be identified easily. In the future, further development such as radionuclide identification feature can be added to the prototype.

1. Introduction

Uncontrolled release of radioactive material can cause adverse effects on the environment and increase health risks for the community. In case there is a radiology or nuclear emergency, to minimize the effect, action needs to be taken in accordance with the level of emergency. When the emergency occurred at a nuclear facility, the facility owner and/or operator shall take an appropriate action. National Nuclear Agency of Indonesia (BATAN) is a government institution which owns and operate three reactor research in Indonesia located in Serpong, Bandung and Yogyakarta. Therefore, in order to ensure public protection, we need to monitor release of uncontrolled radioactive material to the environment.

As part of the preventive measure, BATAN already installed on-line environmental radiation monitoring system in Serpong[1], and periodically monitor the presence of radioactive material in surrounding environment including water body, soil and in the air. In the latter case, the sample is collected and then being analyzed in laboratory. In the former case, a radiation monitoring device installed in the field is continuously measure the radiation level (mainly gamma radiation), and then send the measurement data to centralized server. Currently, number of field measurement device
operated by BATAN is still limited and only available at certain location. Ideally, radiation monitoring devices should be placed on each sector of the wind direction around nuclear facility. In addition, if transboundary radiation release is being considered[2], [3], radiation monitoring devices should be installed across the country.

Several prototypes of radiation monitoring devices for on-line radiation monitoring system has been developed[4–6]. These devices using Geiger-Mueller (GM) detector for measuring the radiation level. Although GM-detector cannot be used to identify the type of radionuclide, compared to scintillation detector, GM-based device is easy to construct and with relatively simple algorithm can be used to measure radiation dose rate. Typically, it has lower sensitivity compared to scintillation detector. These facts motivate us to develop another type of radiation detection device based on NaI(Tl) scintillation detector. This device is simply detecting the presence of man-made radioactive material in the environment.

A prototype of radiation detection device has been constructed and installed around our nuclear facility in Bandung. The device is connected to centralized database server through internet. In this study, the performance of real-time data acquisition and the effect of environmental condition to the device is analyzed.

2. System Overview

Figure 1 shows the overview of online radiation monitoring system which includes radiation monitoring device, data communication and database server. The device based on NaI(Tl) detector that has been developed is shown in the left side of the figure. The device continuously monitors the count rate and then send its measurement result to database server through wired-internet connection which is available as part of our institution’s communication network. Message Queueing Telemetry Transport (MQTT)-based communication protocol is being used to transmit the measurement data from field device to the server. This communication model is widely known as publish-subscribe (Pub-Sub) communication, in which the field device which acts as publisher actively pushed the data to the server at certain interval. In this communication model, the load of the server is low compared to pooling-based system.

![Figure 1. Overview of on-line radiation monitoring system](image)

The following Figure 2 is the photograph of the device prototype installed in Bandung. It uses Ludlum model 44-2 NaI(Tl) detector[7] for radiation detection. The detector has 2.5 cm (1 in) dia. x 2.5 cm (1 in) thick, 175 cpm per µR/hr sensitivity, energy range between 20 keV to 1.5 MeV and operating temperature between -15 to 50 °C. The electronics box consists of power supply, high voltage unit, single channel analyser (SCA)-based radiation counting module, Arduino microcontroller for timer/counter and ethernet communication module. It’s also equipped with temperature and humidity sensor to measure the operating environmental condition.
3. Experimental Setup and Data Analysis
The device is installed in the end of April 2019 and continuously monitor the radiation level as count rate. Upon the first installation, a standard check source is used to verify its response to the presence of radioactive material in the environment. All the measurement data is stored in Relational Database Management System (RDBMS) and can be retrieved for on-line display and further analysis using Structured Query Language (SQL). The successive interval between each measurement was set to 10 seconds. The collected data was exported to comma separated value (CSV) format for analysis. Python programming language was used to analyze the whole data and the results is then being plotted using Matplotlib.

In previous studies, it’s known that the response of scintillation detector is depending on environmental operating condition. In this study, the effect of environmental condition is quantized. The result is then being used to correct the count rate using the following formula

$$CPM_{cor} = CPM_{mea} - F_{fit} + \mu_{CPM}$$ (1)

where $CPM_{cor}$ is corrected count rate, $CPM_{mea}$ is measured count rate, $F_{fit}$ is correction function estimated from experimental data and $\mu_{CPM}$ is the average count rate.

4. Results and Discussion
The device has been installed since the end of April 2019 and continuously collecting environmental radiation data as count rate in count per minute (cpm), temperature in °C, relative humidity (%RH), high voltage applied to NaI(Tl) detector, and cooling fan status. Data acquisition is performed by the microcontroller every 10 seconds and then being pushed to database server located in Serpong through the institution’s internet connection. Measurement data then being stored to PostgreSQL database for further analysis. In this paper, data collected between April 30th, 2019 to August 6th, 2019 is analyzed and presented. Total number of data points is 733,725 records.

Since the microcontroller in the field device doesn’t have real-time clock (RTC) module, timestamp which indicates the measurement time is assigned by the application in database server when data arrived. Time lag which indicates time difference between two successive measurement is
calculated for all measurement data to get the profile of data communication delay between field device and database server. The histogram of the calculated time lag is shown in Figure 3. Ideally, if there is no delay, time lag should be equal to 10 seconds. However, as shown in the figure, time lag is distributed among several intervals, in which 98.916% is between 10 seconds to 20 seconds, and approximately 1% to other intervals. This result shows that there are some delays in the communication between field device and database server. On the other hand, there are 6 measurement data which have time lag greater than 1 hour. In this case, the delay probably caused by power blackout or problem in the internet connection at all. Overall, based on the median value, which is 10.57 seconds, we can conclude that the data acquisition delay is approximately 0.6 second. This value is nearly real-time and acceptable since we are sending data over a shared internet connection.

![Figure 3. Distribution of time interval between successive data acquisition (time lag)](image)

Summary of measurement results for the period of measurement is shown in Table 1. Measured temperature is between 18.9 °C and 44.3 °C, while relative humidity is between 19.4 %RH and 78.6 %RH. The temperature value is different from data published by BPS-Statistics Indonesia[8] in which the temperature is between 18.8 °C and 29.5 °C with average value in April-August is between 23.3 °C to 23.9 °C. The difference is caused by the fact that in this study, the temperature is measured inside the electronic box of the field device which is enclosed by stainless steel. Furthermore, the heat coming from electronic components inside the box also contributing to the rising of the temperature value.

| Table 1. Summary of count rate, temperature and relative humidity for 3 months of measurement between April 30th 2019 to August 6th, 2019 |
|---------------------------------|-----------------|------------------|
| Count rate (cpm)               | Temperature (°C)| Relative humidity (%RH) |
| Minimum value                  | 420             | 18.9             | 19.4             |
| Maximum value                  | 1223            | 44.3             | 78.6             |
| Average                        | 653.09          | 25.6             | 52.2             |
| Standard deviation             | 81.77           | 5.4              | 12.9             |
In order to reduce the processing time, an average of raw measurement values within 1 minute (average of 6 measurement values) is being used in further analysis. Typical time series data for count rate, temperature and relative humidity is shown in Figure 4. The peak value of count rate at April 30th, 2019 (around 11:00 AM) shows the count rate during device test using standard Cs-137 check source. The result shows that the device is able to detect the presence of radioactive material in the environment.

![Figure 4. Time series plot of typical count rate, temperature and relative humidity](image)

Correlation between count rate and temperature or relative humidity is shown in the scatter plot (Figure 5). The figure shows that there is strong negative correlation between temperature and count rate. The presented result is in agreement with previous studies which shows that the response of
NaI(Tl) scintillation detector is affected by temperature[9–14]. The chart also shows weak correlation between relative humidity and count rate. However, this correlation probably due to the relation between temperature and relative humidity value[15–17]. Thus, in this study, only relation between count rate and temperature is being considered.

![Figure 6](image1.png)

**Figure 6.** (a) Fitting result of power and exponential equation to the measurement data, (b) scatter plot of temperature against corrected count rate using fitted power equation $C_p(T)$.

![Figure 7](image2.png)

**Figure 7.** (a) Histogram of count rate before and after correction, (b) time series plot of corrected count rate and temperature

Trendline equation fitted to the scatter plot of temperature against count rate is shown in Figure 6(a). Two equation which are

Power equation: $C_p(T) = AT^{-b}$

Exponential equation: $C_e(T) = Ae^{-bT}$

where $C_p(T)$ or $C_e(T)$ is corrected count rate at given temperature $T$, $A$ and $b$ is constant values that need to be estimated from measurement data. In this study, for power equation $C_p(T)$, estimated coefficients $A = 5717.3$ and $b = 0.652$ with $R^2 = 0.859$, while for exponential equation $C_e(T)$,
estimated coefficients $A = 1223.9$ and $b = 0.022$ with $R^2 = 0.844$. These results show that power equation $C_p(T)$ fits better to the experimental data. This also supported by log-log plot shown in Figure 5(b) in which the relation between log value of temperature with log value of the count rate is linear.

Scatter plot of corrected count rate with power equation $C_p(T)$ is shown in Figure 6(b) while the histogram of count rate before and after correction is shown in Figure 7(a). Histogram shows that the distribution of the count rate was changed after correction while the average count rate is almost the same. Furthermore, from the scatter plot, slightly higher count rate around temperature value of 25°C shows there are several peaks which indicate the existence of radioactive material in the environment. One of the peak is shown in Figure 4, while other peaks can be observed in Figure 7(b). In the latter case, the peak is observed at July 14+, 2019. The count rate for this peak is 812 cpm which is 124% compared to average count rate. After confirmation with the safety radiation officer, we were informed that during the day, an exercise for emergency preparedness was held. During the exercise, standard radiation source was used, and that radiation source was detected properly by the device.

5. Conclusion
A prototype of radiation detection device based-on NaI(Tl) scintillation detector has been developed and installed around TRIGA reactor facility in Bandung. The device continuously measured the count rate environmental radiation, temperature and relative humidity for the period of 3 months. The data was collected every 10 seconds and then being sent to centralized database server. Based on median value of time difference between successive measurement, the communication delay between field device was 0.59 second which is nearly real-time for the system that sending data using shared internet connection. Average count rate was 653.09 cpm ($\sigma = 81.77$). The count rate then being corrected to minimize temperature effect using power equation of $5717.3T^{-0.652}$. After correction, the count rate is relatively stable over time and several peaks which indicate the presence of radioactive material can be easily identified. In the future, a multi-channel analyzer (MCA) and GM-based radiation measurement detector can be combined with the device in order to detect the type of radionuclide and to measure the radiation dose rate.

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