Design of IoT-based Radiation Monitor Area for Nuclear and Radiological Emergency Preparedness System in Yogyakarta Nuclear Area

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Abstract. Yogyakarta Nuclear Area (YNA) is one of BATAN's nuclear facility that has many nuclear facilities such as nuclear reactor, accelerator, irradiator, and waste management system. Due to nuclear accident is potentially occur, YNA has nuclear emergency response program and there is a preparedness system to support this program. Radiation monitoring system is one of utilization to acquire and record nuclear radiation exposure in the facility and its environment. An Internet of Thing based radiation area monitor was developed to improve the system not only to acquire the radiation exposure, but also to distribute the acquired data to the cloud server through the internet network. The distributed radiation data can be utilized to analyze nuclear emergence potential in the nuclear emergency response and preparedness system. The area monitor system was designed as sensor network that consists of Geiger Muller detector and high voltage power supply, signal conditioning system, and Arduino as counter and data processor. Data is acquired by a detector and it is transmitted to the server through wireless network using the node MCU communication module. The receiver station system was developed to acquire data from database server to display the radiation exposure in the environment and to identify radiological emergency status. Based on the chi square test stability method, the developed device has good stability which the probability of \( x^2 \) was obtained 0.75. The validation testing also was done using Sr-90 and x-ray spectrometer as radiation source, and the developed device has been compared using a standard survey-meter. The mean square error of this validation testing was 0.37 and 0.24 respectively for Sr-90 at two difference source distance, while for x-ray spectrometer source the mean square error value was 2.48. For further development, the system will be combined with a smart meteorological system to build the integrated data acquisition system for Nuclear and Radiological Emergency Preparedness System in Yogyakarta Nuclear Area.

1. Introduction
Yogyakarta Nuclear Area (YNA) is a nuclear area that managed by the National Nuclear Energy Agency (BATAN). There are two centers i.e. Center of Accelerator Science and Technology (PSTA) and Polytechnic Institute of Nuclear Technology (STTN). These centers manage and operate many nuclear facilities and installation such as Kartini nuclear reactor, accelerator, electron beam machine, neutron generator, waste management facility, SAMOP reactor, gamma irradiator, and x-ray or gamma camera.
All YNA installations and nuclear facility have nuclear accident potentials that occur a nuclear emergency. KNY nuclear facility permit holder has an obligation to conduct the preparedness management program for nuclear emergency. Nuclear management preparedness not only involve all units under permit holder's responsibility, but it also needs to coordinate with other institutional and stakeholder, especially if the emergency scale reach to be a province or national emergency.

In order to support the preparedness program for nuclear emergencies at KNY, a preparedness system for emergencies was developed which consists of three main parts. First, the data acquisition system to acquire environmental radiation, meteorology, and operating parameters of nuclear facilities. The second is a decision support system software to analyze data acquisition into a machine learning based intelligence data processing. The third system is a distributed early warning system.

Nuclear emergency planning activities depend on computer-based decision support systems (DSS) [1], and this system has been developed since more than a decade ago on nuclear power plants [2]. DSS is a system that aims to support managerial decision makers in structured decision situations. DSS is decision-making assistants to enhance their capabilities and not replace policy makers [3]. DSS have been widely applied to assist decision making in various applications such as medical [4]–[6], business and management [7]–[10] even industry[11]–[15]. Internet of Things (IoT) has been implemented in emergency management systems by utilizing sensor networks, wireless, and mobile devices [16], [17]. This study develops an Internet of Things (IoT) based radiation monitoring device as part of the component of environmental radiation data acquisition in the nuclear preparedness and emergency systems in YNA. IoT-based development is intended to produce radiation monitoring area devices that meet the design principles of industry 4.0 technologies, namely as technical assistance, interconnection, information transparency, and decentralized decisions [18]. This radiation monitor area device is designed to be accessible via mobile devices, while also transmitting environmental radiation exposure data into a database server. The stored data will be used by the next system for radiological analysis to produce decisions regarding nuclear emergency conditions.

2. Research Methods
The developed system is divided into two parts, the first part is a wireless area monitor device and the second is a database server and a web-based application as a data receiver station. In the monitor area device, it consists of a Geiger Muller (GM) detector as a sensor, signal conditioner, high voltage circuit, and a wireless communication and control module. The block diagram of the system developed is shown in Figure 1.
GM detector was used as a beta and gamma particle sensor. It has been characterized that its working voltage was 950 volts. In order to comply this requirement, the high voltage supply module was developed using the circuit as shown in Figure 2. This circuit utilized the CCFL (Cold Cathode Fluorescent Lamp) module which work as an inverter because it was supplied by a direct current (DC) source. CCFL produced an alternating current (AC) voltage output between 600 - 1,000 VAC, then AC to DC inverter circuit was utilized to provide 950 volts DC. The detector produced inverse exponential electrical pulse. Therefore, it needs signal conditioner to convert this pulse into positive square pulses so it can be counted by Arduino counter. The signal conditioning circuit was created using the circuit as shown in Figure 3. The positive square pulses are counted for every 3 second by Arduino as a counter and then it would be converted and represented as a dose rate value. Arduino also displayed the dose rate value locally on the LCD and runs a communication protocol to send the measured dose rate data to the database server over the network using a wireless communication module.

![Figure 2. High voltage power supply circuit](image)

![Figure 3. Signal Conditioning circuit](image)

Arduino Uno was used as a counter system, while the wireless module used the node-MCU module based on ESP8266. The Arduino program was developed to count and to process the pulses into a dose rate value, and it also communicated with node-MCU to transmit and to store dose rate data to the database server. The Arduino program algorithm is shown in Figure 4. On the server side, a PHP program was created to receive date, time and dose rate data from Arduino using the HTTP request GET method. Another function of this server-side program was as an interface that will save data entries into the database and display it to the GUI display through a browser.
The dose rate value was calculated by determining the conversion factor of the count per second with the dose rate value measured using a standard radiation survey-meter. Both developed device and standard radiation survey-meter were used to measure a standard radiation source at the same distance and time. The conversion factor was used by the Arduino program to convert the count per second value into dose rate value in mSv/hour. Device performance was determined by characterizing the CCFL response as an HV module, testing the GM signal conditioning circuit, performing the chi square test, and validating the measurement using X-ray radiation source.

3. Result
The result of an IoT-based radiation area monitor development was an environmental radiation acquisition device as shown in Figure 5. While the results of the web-based software as a monitoring system interface display are shown in Figure 6. The web-based monitoring system consists of two main menus i.e. dashboard menu and the radiation node menu. The dashboard menu was used to display the summary data on dose rates from all devices of wireless radiation monitoring network. While the radiation node menu was used to display the details of each node or radiation data acquisition device. In this menu, the device can be adjusted and configured, and it displayed the detailed radiation data that acquired by each device. The user interface of this menu can be shown in Figure 7.
Figure 6. Web-based user interface of the radiation monitor system dashboard menu

Figure 7. Web-based user interface of the radiation nodes menu

The high voltage module test results are shown in Figure 8. Based on the HV module test results, the factor regulation value can be determined using the following equation.

\[ R_f = \left| \frac{HV_{NL} - HV_L}{HV_{NL}} \right| \times 100\% \] (1)

where \( R_f \) is a regulatory or stability factor, \( HV_{NL} \) is the high voltage value without load, and \( HV_L \) is the value of high voltage using load. According to the testing, it can be determined that the average of the
The regulatory factor is 0,43%. The value of regularity factor which is less than 1% shows that the developed high voltage module has a good stability.

Figure 8. High voltage stability testing result

Figure 8 shows the testing results of the signal conditioning circuit which is used to invert the detector output pulses. Based on the results, the GM inverter circuit had been able to reverse the detector's negative pulse which was simulated through the pulse generator. Pulse generator emits an inverse exponential pulse with a pulse height was 3.84 volts negative and the pulse width was 700 μs. These pulses were then inverted by GM inverter circuit where the output was square-shaped with the pulse height was 8.6 volts and the pulse width were 50 μs. With this pulse height, the pulses can be detected by the counter system of the Arduino, so that the signal conditioning circuit has met the requirements of the counter system.

Figure 9. Testing result of the signal conditioning circuit (GM inverter)

The developed radiation monitor area device was tested for measurement validation with a calibrated survey-meter as a comparison device. The test was carried out using Sr-90 and x-ray spectrometer radiation source. Based on the test results, which is shown in Figure 10 and Figure 11, the mean square error (MSE) values which is obtained for 3cm and 15 cm source distances are 0.37 and 0.24 respectively, while for x-ray spectrometer radiation sources are 2.48. The smaller MSE value indicates that the device has good accuracy in measuring radiation exposure at this distance compared to a calibrated survey-meter.
Figure 10. Result of validation testing using Sr-90 source between the developed device and standard survey-meters in different distance

Figure 11. The result of validation testing using x-ray spectrometer between developed device and standard survey-meter.

The next test result is the stability of the counting carried out using the chi-square test method as shown in Figure 12. Chi square value is determined by calculating using the following equation

$$\chi^2 = \sum_{i=1}^{N} \frac{(x-x)^2}{\bar{x}}$$  \hspace{1cm} (2)$$

Where the value of $\bar{x}$ is the average counts that was 159.74, so that the value of $\chi^2$ can be obtained at 23.21.
Then the $x^2$ value of the calculation results is compared with the chi square table using the degree of freedom 0.90 and 0.10, which is widely used in previous studies [19]. The results of the comparison show that the value of $x^2$ was still in the range of $11.7 \leq x^2 \leq 27.2$, which means this system can be accepted and has well functioned because the probability of $x^2$ value was 0.75 and it was in the range of probabilities from 0.1 to 0.9. So that this system is feasible to use to measure radiation intensity randomly.

### 4. Conclusion

The IoT based radiation monitor area device has been designed to support radiological emergency preparedness system in the Yogyakarta Nuclear Area. This device was designed as sensor network to acquire radiation data from the environment and to store it to the database server. It can be accessed using web-based user interface to monitor and to configure it remotely through a computer network. The developed device has been tested and at overall it has good performance which is shown that its high voltage module has 0.43% average regularity. Based on the chi square test stability method, the developed device has good stability which the probability of $x^2$ was obtained 0.75. The validation testing also was done using Sr-90 and x-ray spectrometer as radiation source, and the developed device has been compared using standard survey-meter. The mean square error of this validation testing was 0.37 and 0.24 respectively for Sr-90 at two difference source distance, while for x-ray spectrometer source the mean square error value was 2.48. For future work, this system will be integrated with the data acquisition of meteorological and nuclear facility operational parameter.

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