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Multi Sensor Data Acquisition System Design for Monitoring the Radiation Dose Based on Wireless Sensor Network

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Abstract

Basically, the negative effects of ionizing radiation are the fundamental reason for monitoring and measuring the environmental and individual radiation exposure. A wireless data acquisition system employing the wireless sensor network is designed to obtain a suitable data processing system (acquisition) from several types of sensor modules. Furthermore, it is expected to be the groundwork for the development of a multi sensor data acquisition system for monitoring the radiation dosage received by several radiation workers in real time. This research was conducted within two stages of process. The first stage was the hardware design that included: architecture, sensor node design, and electronic design. The second stage was the development of software system for data acquisition during the measurement of the dosage or radiation exposure received by each radiation worker. The sensor nodes were designed by utilizing the system components. Each sensor node consisted of an Arduino, a sensor radiation pocket Geiger type 5, and an Xbee. The software in this study consisted of three components, i.e. a software for the initial setting of Xbee namely XCTU, data processing for Arduino microcontroller using C++ programming with IDE (Integrated Development Environment), and a data acquisition system developed using Visual Studio. The system should have been designed more efficiently in terms of time and radiation exposure data collection process for the environments and workers in diverse units, particularly those utilizing the nuclear energy.

Keywords: Multi sensor, radiation protection, real time, WSN

I. INTRODUCTION

The contribution of radiation exposure based on its genesis can be classified into natural and artificial exposures [1][2]. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) explains that the contribution of radiation exposure in this world are composed of 40% of radon natural radiation, 14% of cosmic rays, 18% of external natural, 11% of internal natural, and 14% of medical procedures with the annual average of total dosage in the amount of 2.8 mSv [3][4]. The study and the usage of ionizing radiation, that henceforward is called radiation in the field of medical, began with three important discoveries: X-rays by Wilhelm C. Roentgen in 1895, natural radioactivity by Henri Becquerel in 1896, and Radium by Pierre and Marie Curie in 1898. Since then, radiation has gained an important role, thus it spurs the development of radiology and radiation therapy [5]. As the technology advances, the utilization of radiation becomes more widespread in the field of industries and nuclear reactors. Nuclear reactors are employed in the power plants with the uranium as the fuel and other uses in research (research reactors). In the field of industry, radiation is used for various purposes, i.e. industrial radiography [6]. X-rays are used to inspect the inside of the metal to know the weak point or the defective in metals and welding before the product is sold on the market. Furthermore, the usage of radiation in industry includes the irradiators (machines used to exterminate bacteria and other pathogens in food). The other utilizations of radiation are for testing the solidity of the road and construction material, security checks at the airports, and shipping ports [7].

The utilization of radiation contributes to radiation exposure to the environment, patients, people in society, and workers in radiation sectors. Radiation exposure can induce negative effects on health and heredity (genetic) [8]. The negative effects of radiation based on the dosage level can be categorized as deterministic and stochastic [9]. The deterministic effect occurs when a large dosage of radiation exceeding a threshold value is in contact with the biological tissue or organ. Deterministic effects can be observed immediately like nausea, skin inflammation, burnt skin, cell death, and cataracts. Meanwhile, the stochastic effect is more about the delayed effect and one of the examples is the cancer. The stochastic effect does not recognize the dosage threshold, so that any dosage of radiation received can potentially induce a cancer [10]. Radiation effects on offspring can occur if the cells damaged by radiation exposure are the germinal cells that function to transmit the genetic information to offspring [11].

Radiation cannot be directly observed, thus it requires a radiation monitoring device called a detector. A detector system which is connected with the other electronic devices to measure the dosage of radiation received by an individual is better known as personal dosimeter. The radiation dosimeters currently available are passive and active dosimeters [12].

One example of the passive radiation dosimeters used nowadays is the luminescence detector, TLD (thermo-luminescence dosimeter) [13]. TLD has a small dimension so that it allows measuring the dosage in the form of dots, inexpensive, and available in various forms but unable to display the results of radiation dosage measurements directly. The reading of the radiation dosage stored in the TLD requires a TLD reader. The usage of passive personal dosimeter system requires certain duration of time for monitoring the radiation exposure, i.e. short term (⩾ 1 day) and long term (1-3 months or > 3-6 months). Before knowing the cumulative dosage received by the workers during the usage period, each dosimeter should pass the evaluation process by an accredited dosimeter laboratory. The process of evaluating the dosimeters also needs time for delivery to the designated dosimeter laboratory, thus it can deter the dosage information is to be acquired quickly [14]. An active dosimeter that can display the measurement results directly is called EPD (Electronic Personal Dosimeter) [15].

The measurement results obtained are stored directly in the memory card but cannot be stored directly on the computer. If the radiation dosage received by a radiation worker can be known in real-time, then the evaluation and the documentation of the radiation dosage reception in an institution will be better. Radiation accidents or excessive radiation dosage reception can be known earlier and the evaluation can be done immediately. To overcome this problem, a data acquisition system based on wireless sensor networks is designed for the safety and protection of the radiation workers.

Magalotti et al. developed a wireless dosimeter system that was implemented in the field of Interventional Radiology (Irad) to monitor the dosage absorbed in various parts of the operator's body during the Irad procedure [16].

Nagatani et al. developed a portable radiation detector to gather and send the radiation information using a sensor network system (Wireless Sensor Network) [17]. The detector is used to monitor the radiation exposure due to the Fukushima nuclear power plant accident. Basically the negative effects of ionizing radiation are the fundamental reason for monitoring and measuring the environmental and individual radiation exposure [18].

A wireless data acquisition system employing the wireless sensor network is designed to obtain a suitable data processing system (acquisition) from several types of sensor modules. Furthermore, it is expected to be the groundwork for the development of a multi sensor data acquisition system for monitoring the radiation dosage received by several radiation workers in real time.

II. METHODOLOGY

This research was conducted within two stages of process. The first stage was the hardware design that included: architecture, sensor node design, and electronic design. The second stage was the development of software system for data acquisition during the measurement of the dosage or radiation exposure received by each radiation worker.

A. Hardware Design for node sensor

The architecture of the data acquisition system based on the wireless sensor networks for the safety and protection of radiation workers utilized the Geiger type 5 pocket radiation sensor for reading the radiation dosage received by radiation workers. Arduino with AT-Mega microcontroller was employed as the processing unit and connected to the software system equipped with Xbee module communication devices[19]. The design of nodes sensor is shown in Figure 1.

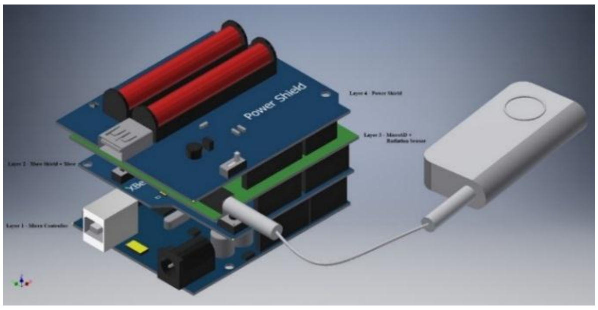


Figure 1. Environments condition for traffic monitoring

Design of nodes block diagram. The sensor nodes were designed by utilizing the system components. Each sensor node consisted of an Arduino, a sensor, power supply, and an Xbee.

Arduino as a microcontroller received input from the radiation sensor that counted the nuclear radiation received by radiation workers. One sensor node consisted of the microcontroller integrated with the Xbee module. The results of data collection obtained were stored in micro-sd, along with the process of sending data to the coordinator by matching the time with Xbee and then entering the data acquisition system displayed on the PC.

The radiation sensor used was the Pocket Geiger type 5. The specification of Pocket Geiger type 5 interface is presented in Figure 2.

Figure 2. Radiation sensor and the interface specification

The Pocket Geiger had an on-board DC boost circuit, thus it could be supplied with a friendly 3V to 9V. Using only 30mW (10mA @ 3V), it was a very low power [20]. Pocket Geiger type 5 used a sensor made of photodiode with the active area of detector (10 mm x 10 mm) or 100 m^2 [21]. This radiation sensor was sensitive to gamma rays and beta particles, with a measurement range of 0.05 µSv/hour to 10 mSv/hour [20]. The transmission of radiation exposure data received by the sensor utilized the radio frequency device type Xbee module. The

Xbee module used was based on IEEE 802.15.4/Zigbee WPAN standards developed by DIGI international companies.

Sensor nodes were employed to collect radiation exposure data or radiation dosage sent to the coordinator and displayed on a computer screen afterwards presented in Figure 3.

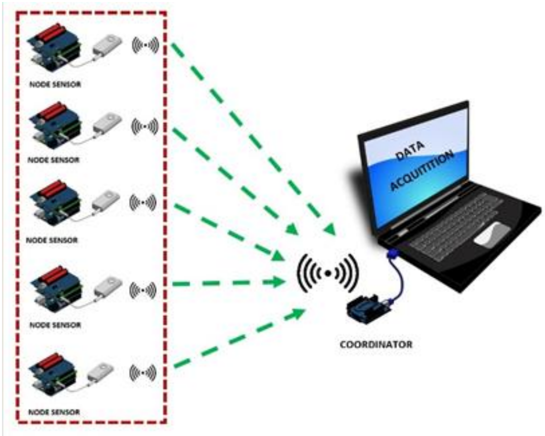


Figure 3. Radiation dosage sent to the coordinator and displayed PC

B. Software design

The software in this study consisted of three components, i.e. a software for the initial setting of Xbee namely XCTU, data processing for Arduino microcontroller using C++ programming with IDE (Integrated Development Environment), and a data acquisition system developed using visual studio.

III. RESULTS AND DISCUSSION

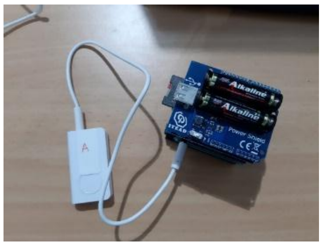
The system built consists of one coordinator and five independent radiation sensor nodes. Sensor node that are designed are limited due to the limitation of radiation sensors and other components. The system designed allows an unlimited number of radiation sensor nodes, therefore when needed for monitoring radiation exposure to many workers, this system can be developed.

A. Result of sensor nodes hardware implementation

Designing sensor nodes minimizes the use of Jumper by building Printed Circuit Board (PCB) (Figure 4) and adjusting the size of the microcontroller, in this case the Arduino Uno.

Figure 4. PCB a node sensor

Furthermore, this PCB is connected to the Arduino Uno microcontroller, Arduino Xbee Shield which has fixed Xbee module type Xbee S2C Pro, SD Card module, power shield completes with voltage source and radiation sensor. The unity of all components and PCBs is called a sensor node, as shown in Figure 5.



Upper view

Side view

Figure 5 Results of sensor node implementation

B. Result of the coordinator hardware implementation

The coordinator consists of one Arduino Uno, Arduino Xbee shield, one xbee S2C Pro installed on the xbee shield and a computer. The computer functions as a data processing unit as well as a voltage source for the coordinator. The result of the hardware implementation for the coordinator is shown in Figure 6.

Figure 6. Results of hardware implementation for the coordinator

All data derived from sensor nodes is collected into a database through this node. Coordinator will be connected to another device as the server, in this case a computer is used as the local server. Data in the database will be displayed through the information system.

C. Results of software implementation

Software is needed to run the hardware that has been designed, namely the sensor node and coordinator. There are three software used in this study, namely (1) XCTU is used to configure the Xbee module which is used to be able to connect between sensor nodes and coordinators and to test the performance to the designed wireless sensor network system. The result of testing the connection between the sensor nodes and the coordinator is shown in Figure 7.

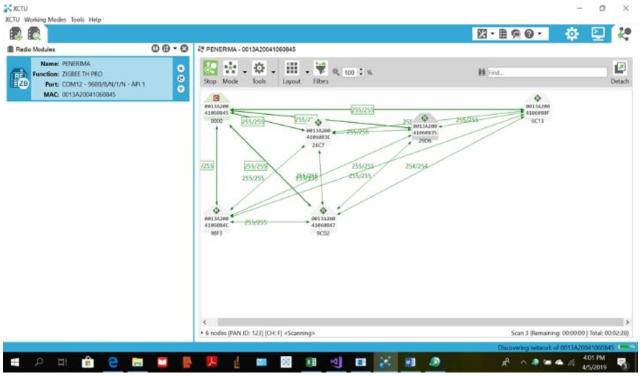


Figure 7. Result of connectivity testing between sensor nodes and coordinators using XCTU

(2) Arduino IDE (Integrated Development Environment) is used to facilitate the writing of C++ language programs and upload programs developed at each sensor node and coordinator. Software programming on sensor nodes and coordinates is different. The program sensor node is used to run the radiation sensor function so that it can be sent to the coordinator with the help of the Xbee module. (3) GUI (graphical user interface) is developed using visual studio in a data processing unit (PC) (Figure 8).

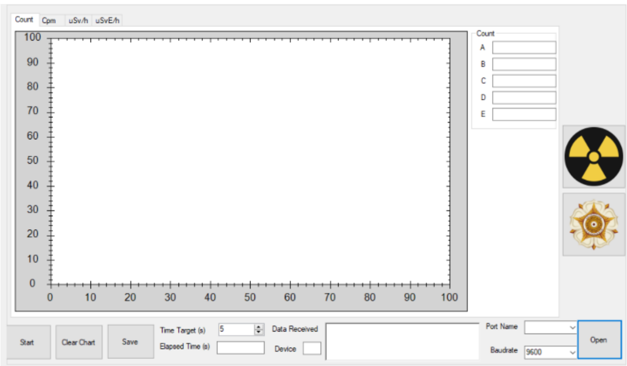


Figure 8. Graphical user interface (GUI) monitoring radiation dose

Data is sent from the sensor node to the coordinator and displayed in the GUI in the form of string. This string data is collected in the form of packages separated by commas. One package consists of seven data as presented in Table 1.

Table 1. Message format / data package

header	address	count	cpm	µSv/h	µSvE/h	end

The first data is the header which is the initial data marker, the address it the address of the data for example for data from sensor A, then it will be addressed to A. next is data count, cpm, µSv/h, µSvE/h, and finally end. This end indicates that the data has been sent entirely. This method is needed in order for data from each sensor node not to collide with each other and be exchanged. So that we can ensure that the data really comes from the desired detector and ensures all data has been sent.

A, B, C and E represent dosimeter data A, B, C, D and E. Data are collected and displayed in the graphical form and then each radiation dose value obtained from each sensor node can be displayed as graphs or numbers in TXT format.

D. Result of experiment

Before testing is carried out using a radioactive source, a detector response test is done against background radiation (Figure 9).

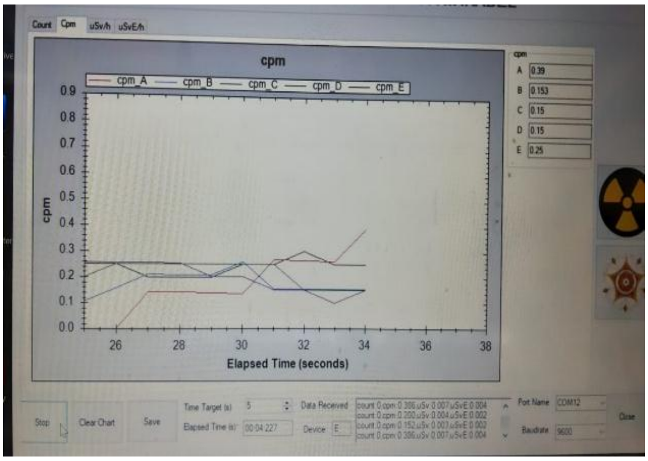


Figure 9. Background radiation is displayed in the GUI

Testing one sensor node to change the time of sending data to the coordinator. This is carried out to find out the detector response that is used against transmission time alteration. The results of this test are done by varying the time from 5 seconds, 10 seconds, 15 seconds, 20 seconds to 40 seconds, as shown in Table 2.

Table 2. The results of testing the system against changes in data transmission time

No	Change in transmission time (s)	Average detector response (CPM)
1	5	1640 ± 60
2	10	1620 ± 50
3	15	1650 ± 60
4	20	1600 ± 60
5	25	1590 ± 60
6	30	1580 ± 40
7	35	1590 ± 60
8	40	1590 ± 60

The detector position is set 5 mm from the position of the radiation source (always made fixed) and the data used consists of 100 data. In table 1, it can be seen that there is no significant effect of changing the time of transmission data against detector response. The detector response to time changes for each 5 second data collection is shown in Figure 10.

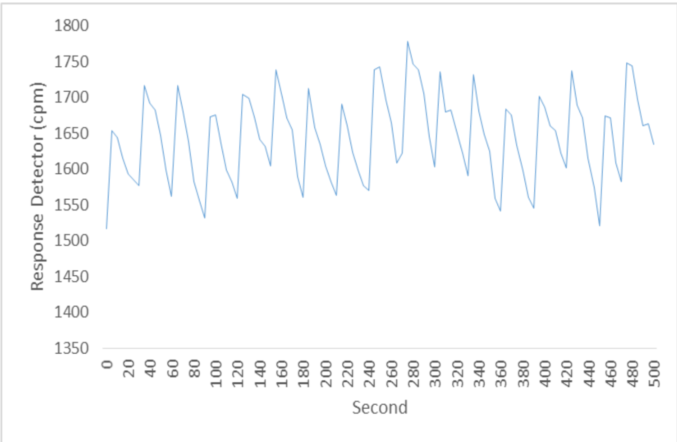


Figure 10. Detector response against time

Figure 10 describes the response detector for changes in observation time. This detector is exposed to radiation from the source Cs-137 which produces gamma radiation. The detector response looks up and down due to the integration of Cs-137 atoms that emits gamma radiation energy spread in the air. This causes the detector response to sometimes increase and decrease. Then the detector response test in multi detector is shown in Table 3.

Table 3. Response multi-detector

Detector	Response (cpm)
A	4
B	57
C	55
D	14
E	3

Table 3 represents that the highest value is found in detector B and C while the lowest value is in detector E. This is in accordance with the expected, in which if the detector is near the radiation source the response cpm increase as shown in Figure 11.

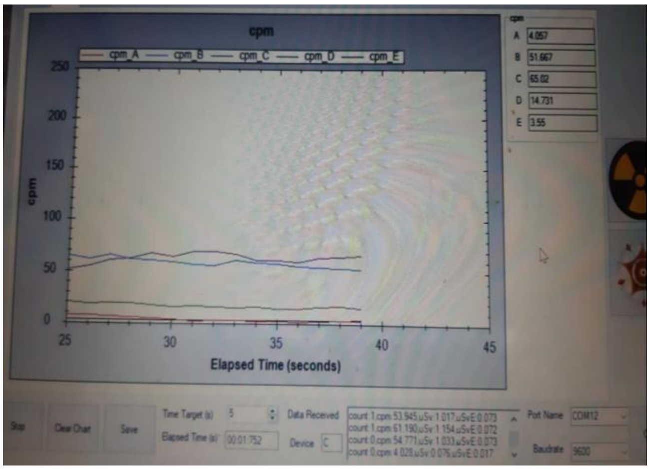


Figure 11. Response of multi-detector against radiation source

Detector B and C are positioned close to the radiation source so that they have a high cpm value. This indicates that radiation dose received by the detector also increases. On the contrary, other detector is positioned away from the radiation source so that the detector response becomes low namely detector A of 3 cpm.

This designed system is able to collect measurement results of radiation exposure from multi detectors using the wireless sensor network (WSN). Each sensor node or detector sends the radiation exposure value to the coordinator. The coordinator is connected to a computer that has been equipped with a data acquisition system. This system can collect radiation exposure data from several radiation workers every one minute or can be arranged in the GUI. When the save button is pressed, all results of radiation exposure will be displayed in TXT format and the radiation exposure data can be known in real time.

This provides advantages for radiation protection for the environment, radiation workers, who use nuclear power. If there is a significant increase in radiation exposure, it can be known earlier, so that negative risk of using nuclear radiation can be reduced. The radiation exposure data obtained can be stored or printed, if the data needed for evaluation, it can be obtained immediately.

IV. CONCLUSION

In this study, each sensor node designed consists of a microcontroller, a radiation sensor of the Geiger Pocket Type 5 and an IEEE 802.15.4 / Zigbee standard wireless module. The system should have been designed more efficiently in terms of time and radiation exposure data collection process for the environments and workers in diverse units, particularly those utilizing the nuclear energy.

If there is a significant increase in radiation exposure, it can be known earlier, so that negative risk of using nuclear radiation can be reduced. The radiation exposure data obtained can be stored or printed, if the data needed for evaluation, it can be obtained immediately.

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